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The WAYS of FISHES

The WAYS of FISHES

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WITH

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FOR DOROTHEA AND BILL
who made it possible for us to work

PREFACE

THERE are forty thousand different kinds of fishes, nearly twice as many as the varieties of birds, mammals and amphibians—all the other vertebrates—put together! Individually they are innumerable, the most abundant form of vertebrate life found either around the shores or in the fresh waters of all the continents and the islands on the globe. They live from down in the depths of the sea, to up above the timber line on high mountains. Some are at home in an 109-degree temperature of hot springs; others flourish in the near-frozen waters of the Arctic and Antarctic Oceans.

Adult fishes range in length from one third of an inch to more than forty-five feet; in weight from two or three grams to twenty-two tons. Their coloring is as varied, brilliant and beautiful as that of the butterflies (indeed, I believe more so, but an entomologist might not agree), and some glow with a luminescence lovely and enchanting.

Parts of fishes, frequently mentioned, are shown in Figures 1 and 2. Other technical terms are explained the first time they are used.

Not all are creatures who can exist only in water and move only by swimming; some walk, some fly; some breathe air, some water. There are fishes with eyes divided somewhat like the bifocal lenses of spectacles, for different uses; the upper part for vision in air, the lower for vision in water.

Some of them have habits resembling those of humans; fishes, for instance, as strictly vegetarian as members of a non-meat-eating religious sect; others that catch their dinners with fishing rods. The habits of other mammals, too, have their counterparts. There are fishes that burrow like moles, hibernate like bears, and fight like tigers.

Even temperamentally, fishes are not of a piece. Some are placid; others are nervous and easily irritated. Among them are the timid and fearless, the lazy and energetic, the mild and the bloodthirsty.

This book will make no attempt to give a comprehensive picture of the behavior of fishes. It will simply tell something about the habits of those fishes which seem to me the most unusual and interesting. My object in writing it is to share with others who are not ichthyologists, at least a little of the enjoyment my colleagues and I get out of knowing the bizarre, astonishing and manifold ways of our favorite animals.

LEONARD P. SCHULTZ

Washington, D. C.

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Dr. David H. Dunkle, Associate Curator of Vertebrate Paleontology, United States National Museum, kindly prepared the list of fossil fish groups up to the superorder Teleostei, for which the authors are very grateful.

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INTRODUCTION

FISHES mean different things to different people. To the residents of sea-coast villages, those weatherbeaten men who set forth daily or seasonally in fishing boats, and the women who wait for them to come back safe, they are living and livelihood. To the sportsman, casting for trout while the clear cold waters of a mountain stream swirl about his legs, or giving and taking with a deep-sea game fish convulsive at the end of his line, they are a means of play; this they are, also, to aquaria enthusiasts whose hobby is breeding them. For housewives, they are an important form of food, or a variant in the menu, or a special delicacy; for some primitive peoples they are the staff of life.

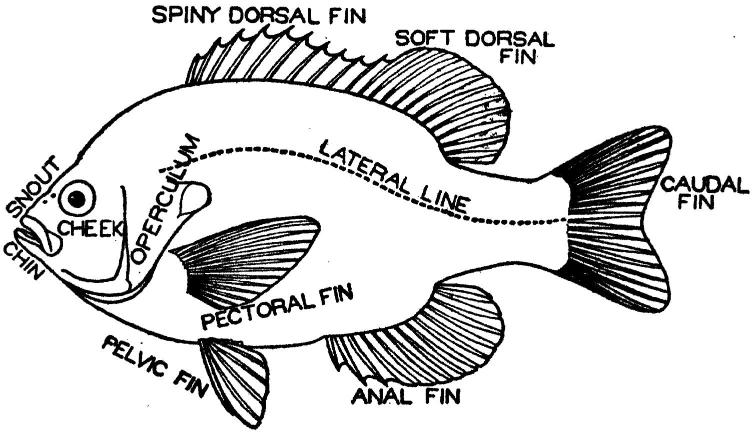

FIG. 1. A sketch to illustrate the names usually given to various parts of a spiny rayed fish, such as the bluegill sunfish of the eastern United States.

However, unless he has a special recreational or utilitarian interest in fish, the average person sees them as little more than silent, uninteresting, glassy-eyed, cold-blooded, swimming creatures having scales and many small bones—and about as much personality as turnips!

To me, fishes are the most fascinating and remarkable form of animal life in the world.

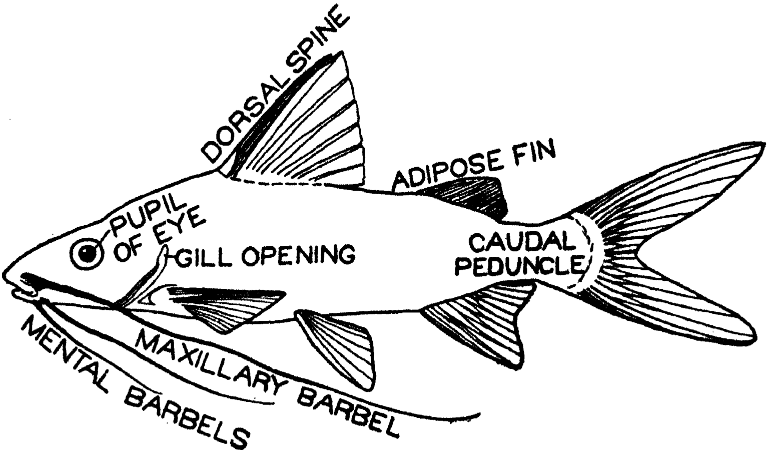

FIG. 2. A sketch of a catfish to illustrate the names applied to various structures found on soft rayed fishes.

I became an ichthyologist because as a boy in Michigan I was interested in everything that lived and grew, in bugs, moths and butterflies. The animals on the farm where I lived were my pets. Not until I went to Albion College in my home town did I begin to study fishes in the Kalamazoo River. Soon I wanted to find out more about them. And the more I learn about fishes, the more I marvel at their variety and the color and drama and odd quirks and excitement of their ways.

1

MIGRATION

FISHES are restless creatures, constantly on the move. They may wander short distances or commute daily in search of food, some between deep water and the surface of the sea; many make occasional long journeys. When their traveling swells into a mass movement, and large numbers of them, at certain seasons of the year, go great distances in the same direction and for the same purpose, it becomes a true migration like that of birds.

When fishes migrate, they do so for one of two purposes. Some, among them the tunas and albacores, follow the schools of mackerel, herring, sardines and other smaller fishes upon which they feed; they appear in swarms in an area and then, when their food supply is depleted, disappear in search of another hunting ground. Others, like the salmon, eels and lampreys, migrate to reproduce, or spawn. There are two groups of these, the anadromous fishes and the catadromous. The former, such as salmon and shad, go from salt water to fresh water for their spawning; the latter, among them the fresh-water eels, the gobies, and certain species of the Galaxiidae of the southern hemisphere, reverse the procedure and make their way in hordes down fresh-water rivers to swim off into the sea.

The Epic of the Eels

Among the catadromous fishes the most spectacular migrant is the common fresh-water eel (Figure 3) found in the Atlantic slopes of Europe and North America. Indeed, its life history is one of the most impressive and adventurous in all natural history, and the story of how this life history came to be learned is in itself almost equally astounding. The details of the eel's migration are as well known now to naturalists as the details of the migration of our people from East to West are known to historians, but for centuries they were only disconnected material for a mystery story. From Aristotle on down through the years until the twentieth century, nobody knew the answer to the persistent question, "Where do eels spawn?"

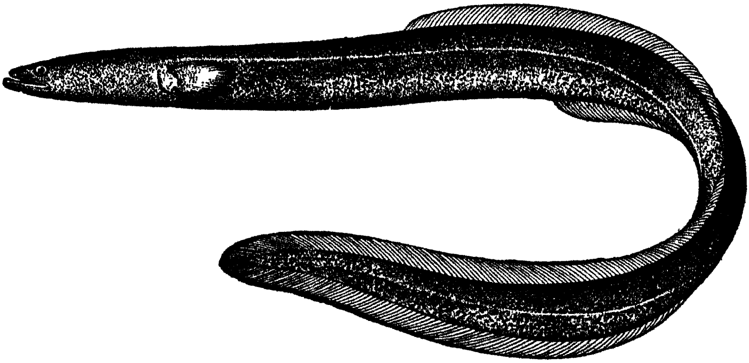

FIG. 3. The fresh-water eel, *Anguilla,* occurs in the North Atlantic ocean and in coastal streams; in the Western Pacific other species of *Anguilla* live, but along the Pacific coasts of the Americas there are no fresh-water eels.

Certain observations, of course, had been made; there were certain clues, although they did not fit together into a solution. Each autumn people saw large numbers of adult eels going down the rivers and, although many heading out to sea were caught in the salt waters near the coast, no adult was ever seen returning to its original fresh-water home. Each spring myriad young eels, three to four inches long and no thicker than a match or the lead of a pencil, would appear along the coast in search of river mouths; so many that catching these eel fry, or elvers as they came to be called, became quite an industry. But there was not even the basis of a guess as to where they were born, and it was assumed (incorrectly!) that these elvers were the offspring of the eels who had gone down the rivers the previous autumn.

In 1896 a paper published by two Italians, Grassi and Calandruccio, set the world of ichthyologists and naturalists agog with excitement. The elvers, this study revealed, were not infants at all; actually, they were well along into childhood. For Grassi and Calandruccio, almost accidentally at first, had discovered that there were still younger eels, looking as little like their older brothers and sisters or parents as a newborn baby—despite the delusions of its doting relatives—resembles a full-fledged human being. These tiny creatures were leaf-shaped, not tubular like their elders, and transparent as glass; and the earliest naturalists, who had named them leptocephali, had never associated them with eels.

The Italians had evidence to back their findings. One day, when they were dragging in the Mediterranean for the small marine organisms known as plankton, they picked up in their cone-shaped, fine-meshed plankton nets some curious little creatures neither exactly leptocephali nor elvers, but something in between. Grassi and Calandruccio's coldly scientific report does not record what they said or how they acted at first sight of this piscatorial missing link, but since they were Italians they undoubtedly exclaimed and gesticulated in wonder and delight, for their find was enough to send any naturalist's mind and imagination whirling. At any rate, they followed this chance catch with netting and collecting more specimens, and they established the fact that when leptocephali reach about three inches they metamorphose into elvers.

Other men, stimulated by the emergence of this clear new clue out of the obscurity of the eel's life history, made further studies. After a while it was known that the leptocephali occurred only out at sea, never close to the coast or in river mouths. But it seemed as if research had gone a step forward only to go two steps back, for the eel question had a puzzling new angle. If adult eels laid their eggs close to shore, which seemed logical, the newly hatched should have been found there; yet over a period of years one study after another made it apparent that, wherever the still unknown breeding place of the eels might be, it was certainly far from the coastline. The farther out to sea the leptocephali were collected, the smaller and younger were the specimens.

So the matter rested, until in 1905 the International Council for the Study of the Sea assigned to Denmark the systematic investigation of the eel's life history, migration and spawning. Because eels are an economic asset, and because fisheries may become depleted when the habits of fishes are not well enough understood to have the best regulations made for their preservation, the Danes willingly undertook the task. The government appointed Dr. Johann Schmidt, doggedly determined biologist and oceanographer, and Director of Denmark's Carlsberg Physiological Laboratory, to solve the age-old eel mystery.

It was a formidable job to which he devoted himself until his death in 1933. For one thing, it threatened to be too expensive for any scientific body or even the Danish government to finance. From Greenland to Iceland to Norway, from the Black Sea and Suez to Rio de Oro, Africa, thence to the Canaries across the Atlantic to Central America and on up to Nova Scotia, a fleet of hundreds of research ships would be needed so that plankton nets could be hauled all over the Atlantic Ocean and millions of gallons of water be strained in order to collect enough specimens of leptocephali to determine from where the tiniest came and whence they went as they developed.

Dr. Schmidt overcame this first obstacle to his investigation by enlisting the co-operation of hundreds of captains of commercial ships plying the Atlantic Ocean. He supplied them with plankton nets and they supplied him with specimens. Among these was not one adult eel, no elvers; but thousands upon thousands of little leptocephali were collected in assorted sizes.

Incredible as it may seem, Dr. Schmidt and his assistants carefully prepared a notation as to where each one had been picked up, and the number of its vertebrae and fin rays. For a while it seemed that the complication of there being two species of eels, the European and the American, spawning somewhere in the Atlantic, might make the eel question perpetually insoluble; for even were it ascertained where the newly hatched originated, who could tell whether their parents had migrated from the East or from the West? Then one happy day Dr. Schmidt, analyzing numerous specimens from the same haul, found that they fell into two categories, the one having more vertebrae than the other. Further research established the fact that the European eel averaged

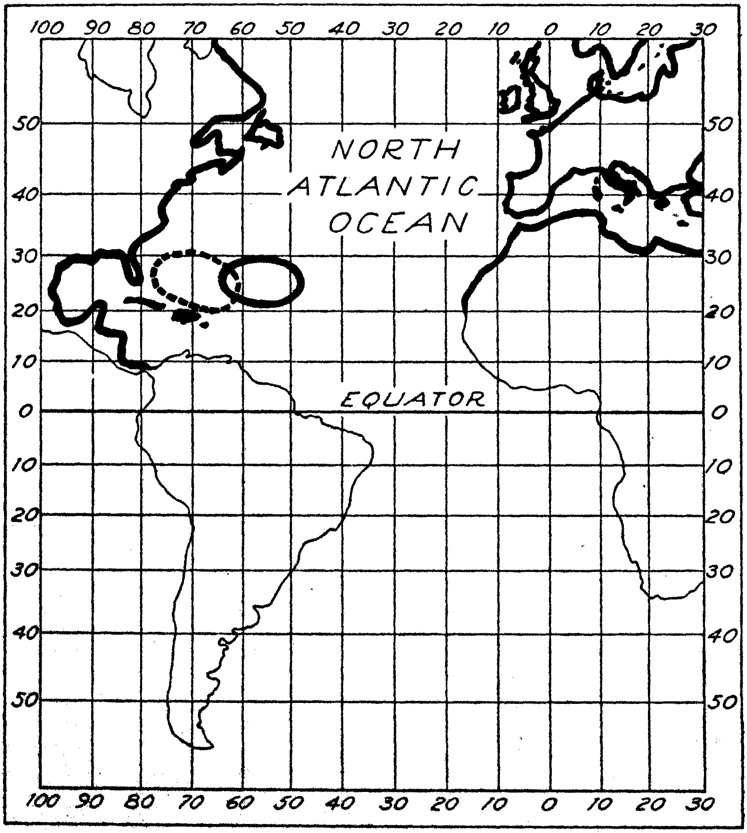

FIG. 4. The distribution of the fresh-water eel, *Anguilla*, along the shores of the North Atlantic Ocean is indicated by the heavy black line. The broken line in the North Atlantic shows the location of the spawning grounds of the American eel and the heavy black oval line that of the European eel.

seven and a half more vertebrae than the American, and the parentage of each kind could henceforth be determined by a count of their tiny bones.

Now all Dr. Schmidt's dry figures added up to the life history of the eel, and the long-sought answer to the eel question (Figure 4). He found that specimens of European leptocephali diminished in size as their distance from Europe grew greater, until, in an area 50 to 65 degrees west longitude and 22 to 29 degrees north latitude, from the sea's surface to 900 feet below, occurred the tiniest ones of all. This area is somewhat southeast of Bermuda near the Sargasso Sea, the warmest water in the North Atlantic. And since these smallest of the leptocephali were all collected from the early spring to summer, spawning time was discovered as surely as spawning place.

American eels spawn closer to home, somewhat to the westward, in an area north of the West Indies and south of Bermuda. Their smallest, most recently hatched offspring were taken during the winter months.

Except at their birthplace, the European leptocephali were found no deeper than 150 feet in the warm surface water of the Gulf Stream. They have no special power of locomotion in any one direction, and, feeding on plankton, drift with the Stream toward Europe. How many of the helpless little creatures fall prey to other marine animals on their long and perilous journey, nobody knows; but those who survive reach the middle of the Atlantic by their second summer. By the third summer they arrive off the coast of Europe, as large as they will ever be as leptocephali (Figure 5). During the autumn of their third year and the following winter they turn into elvers, miniature editions of adult eels and fully endowed with the power to swim by means of undulating their long, slim bodies.

The elvers move into fresh water; then, at this point in their development and travels, the sexes part company. For years thereafter, they live lives as separate as if they were cloistered. The males remain in the brackish waters near the river mouths and estuaries while the females swim far upstream into headwaters. Both eat ravenously, devouring crabs, shrimps, worms, fishes, clams, snails, and aquatic plants, but despite their more prolonged and strenuous travels, the females put on more weight and grow

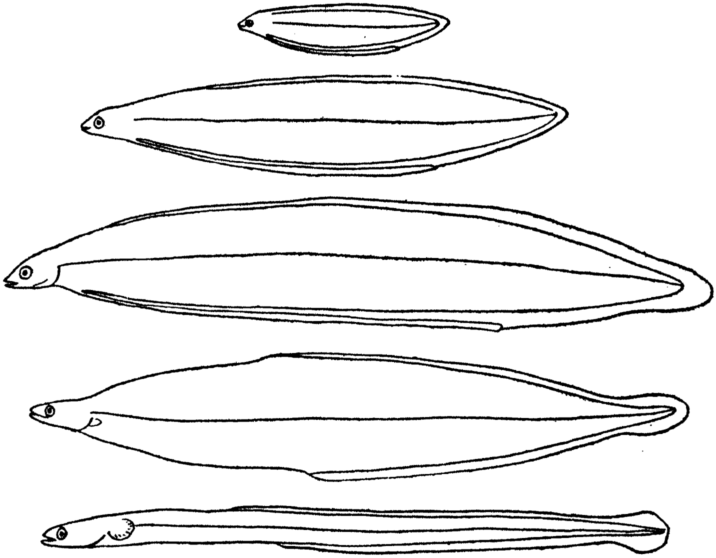

FIG. 5. The young larval eels, leptocephali, go through a remarkable change or metamorphosis as they transform into the adult eel, even shrinking a little between the transparent ribbon-like leptocephalus and the elver stage at the bottom of the figure. (Modified after Schmidt.)

much larger than the males, sometimes attaining four feet as against the males' two. The length of the females' sojourn in the interior of the Continent varies with food supply and climate, but it is no transient one, for it lasts anywhere from five to twenty years. In an aquarium in the Jardin des Plantes, Paris, one lived thirty-seven years.

When adult eels reach sexual maturity they grow darker, lose their voracious appetites, and, in their last great journey, begin their downward migration to their breeding place. It is awesomely mysterious how they manage to find their way to it through the vast 3000 miles of ocean water they traverse.

No one has ever collected an adult fresh-water eel far out at sea, and no one really knows their route or at what depth they swim. Perhaps breasting the current of the Gulf Stream guides them into warmer and warmer waters, but all we can say with certainty is that near the Sargasso Sea they fulfill their destiny, and make no return trip.

The American leptocephali, with less distance to cover than the European, and with equally nice co-ordination of time needed to reach the shore and stages in development, grow up much faster. By autumn of their first year they have attained their full larval size and have reached the North American coast; the following winter they are elvers, and move into fresh waters that spring. From then on their story is a repetition of that of their European relatives.

There are no fresh-water eels in the Pacific slopes of North and South America, but several species occur in the Western Pacific and Indo-Pacific regions. We know that they disappear into the Pacific Ocean. We know, too, that they migrate upstream, and in greater numbers than are seen where civilization has decimated the fishes. Dr. A. W. C. T. Herre, Curator of Fishes at Stanford University, observed an "eel fair," a migration of millions, in the great Sepik River of New Guinea. At Marienberg, where the Sepik is half a mile wide and five to twenty feet deep, Dr. Herre saw it so thick with elvers they could be scooped up by basketsful; two days later, only a few laggards remained and the rest had passed upstream.

But, tantalizingly, we know nothing about where the Pacific eel spawns, nor how long it takes its young to develop from leptocephali into elvers, and from elvers into adult eels, nor what distances either young or old travel. The life story of the Pacific eel may be as remarkable as that of the European and American; its migration may be equally far-flung and heroic. It will take another Dr. Schmidt to tell us about it, and perhaps he exists in the person of some now obscure young university student who, with time and patience, will give us another epic of the eels.

The Ancestral Homes of Salmon

Of the two groups of fishes migrating to spawn, the habits of the anadromous are more generally known, not only because so many of them are familiar edible fishes—shad, salmon, trout, whitefish, sturgeon, smelts—but also because the migration of salmon, especially, has been much publicized.

Other anadromous fishes have interesting quirks in their habits of migration. For example, the sea lampreys, parasites who feed on the blood of larger marine fishes, do not migrate until they have gorged themselves for several years. So many Eulachons or candlefish (a Columbia River smelt) migrate together that at spawning time in the Sandy River of Oregon they can be caught with such uncomplicated "tackle" as rakes and bedsprings. Nevertheless, even to me, for whom natural wonders are in the day's work, the popular attention given to the salmons' migration seems merited.

Of all the fishes salmon have the strongest homing instinct, returning from the sea, generation after generation, to where they were born and grew up; not only to the very river but also to the very branch of it where their parents and their parents' parents before them spawned. It is as if they were humans who as adults leave their ancestral homes to go forth into the world, but invariably return to them to marry and give birth.

The Pacific salmon also go home to die—for their lives end soon after they have spawned. Each of the five North American species has a remarkably set pattern of migration. The pink salmon terminates its journey from the sea only a few miles beyond river mouths. The red salmon's homing instinct takes it only where there are lakes in the course of the stream system. The coho, or silver salmon, and the chum, or dog salmon, spawn far upstream. Greatest migrant of them all is the king salmon; as its name indicates, it is the long-distance champion.

Through tagging experiments, ichthyologists have been able to determine the extent of salmons' journeys. There are several methods of tagging fish: to clip certain fins when they are young, to attach tags to their jaws, gill covers, or the tails of adults or to insert them through belly-slits. Many king salmon thus identifiable have been picked up 1000 miles away from where they were tagged in the sea; in the Yukon River of Alaska, some have been found at twice that distance.

Going back as they do to reproduce at the same place through unnumbered centuries and countless generations, salmon of the same species and in the same area, but homing in different streams, have developed differences from their neighbors in streams perhaps no more than twenty miles away. Although these distinctions, such as the number of their scales, are too slight to be noticeable to the average fisherman, they are recognizable to expert investigators. Obvious to anyone, however, are the changes which occur in the appearance of salmon during migration. While adult salmon are still living in the sea, they are usually rather drab, with dark backs and silvery sides, but as sexual maturity and the time for mass travel approach they brighten, many turning brilliant red when they reach fresh water. As they go up the streams and rivers the males develop hooked noses and humped backs; although the humped-backed salmon was named for this characteristic, actually all Pacific salmon have it to a greater or lesser degree.

So powerful is the homing instinct of the salmon that it persists even in species which have been landlocked over the ages, and which have lost the habit of ever leaving fresh water for salt. Lake red salmon, like their seafaring relatives, return to reproduce in the streams where they were born. In their relatively circumscribed world a lake has taken the place of the sea; but for a salmon, when it is the season to spawn, nothing can substitute for its birthplace.

Many fishes do not make long journeys, but all move some time, in some way. How they move differs amazingly.

2

LOCOMOTION

WERE there a kind of maritime Olympic Meet, with all the fishes of the world represented among the contestants, the athletic events would not all have to take place in the water nor need they be limited to swimming. There could be marathons on land, races and jumping contests in the air. For

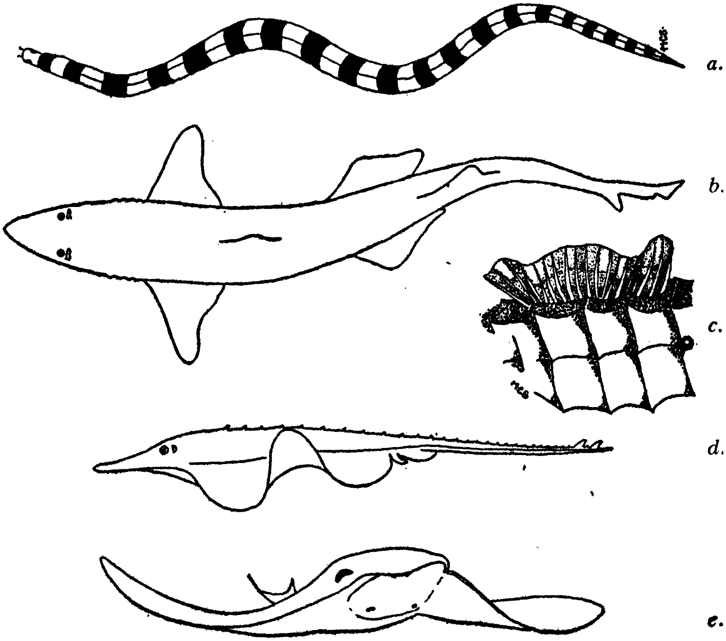

FIG. 6. Various swimming movements of fishes. *a*. The full-wave motion of a snake eel. *b*. The half-wave motion of a shark. *c*. Wave motion in the dorsal fin of a seahorse (after Breder). *d*. Wave motion in the fins of a skate. *e*. Fin motion in a cownosed ray.

there are fishes able to move themselves from place to place not only by swimming but also by walking, skipping, burrowing, leaping or flying.

How Fishes Swim

True, for the majority, locomotion (Figure 6) through water—that is, some form of swimming—is the characteristic and only way they have of escaping danger, finding their mates, seeking food or cleaner water, or for that matter moving about just for the fun of it. This is not news to anyone; but perhaps it is news that in all the most familiar streamlined kind of fishes motive power is chiefly supplied, not by the paired fins, but by the powerful tail, which moves back and forth from side to side. The paired fins are used for steering, balancing, braking and for fine, slow movements. Jet propulsion, the ejection of water out of the gill openings, also is a means of locomotion.

Speediest of the fishes are those whose tails are new-moon shaped and have narrow caudal peduncles. Among them are a few species of sharks which frequently keep pace with fast-traveling ocean liners, while some of the tunas and the swordfish have been observed speeding along at the rate of a mile a minute. Salmon can travel upstream thirty to forty miles a day.

In sharp contrast is the slow motion of another group of fishes, which includes sea horses, pipefish, puffers, trunkfish, rays and skates. These use their paired and median fins for motive power in a manner that resembles the sculling of a boat. The eye cannot follow the speed of the wave motions that go through the dorsal fins of sea horses—about ten per second (Figure 7) according to high-speed movies made by Dr. Charles M. Breder, Curator of Fishes, American Museum of Natural History. Yet for all this expenditure of energy it takes one of the little creatures about five minutes to cross a bathtub!

Nature has compensated, however, in various ways for the handicap of slow locomotion. As protection against the enemies from whom they would have difficulty fleeing, some of the fishes in this group of swimmers are encased in bony armor, plates or heavy scales. Others have an array of porcupine-like, long, sharp spines and still others are poisonous.

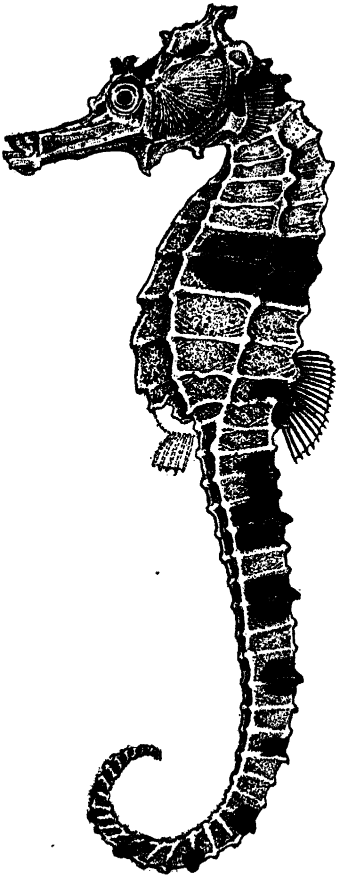

FIG. 7. The seahorse, *Hippocampus*.

Many of these fishes have survived for millions of years. As a matter of fact, they represent a higher, more specialized stage in evolution than the streamlined fishes, which are the more primitive type.

¶ A third group of fishes, the eels and those that are eel-like, propel themselves neither by means of tails nor fins (Figure 6b). These swim with wave-like motions of their whole bodies, undulating through the water as snakes move undulatingly along the ground.

Many fishes do not always swim vertically, but will turn themselves over or upside down to worm their way around obstacles. Such fishes are almost impossible to trap. The butterfly fish and surgeonfish of the South Pacific, for example, are so accustomed to getting in and out of tight places about coral heads that they will practically always find their way out of a trap's narrow opening.

Another South Pacific fish, the little *Gramistes,* has the trick of zigzagging. Black, with six yellow streaks along its sides, it looks as if it were being borne back and forth like a leaf by the surging water while actually this results from its own motions. But it is neither so helpless nor so involuntarily erratic as it seems. Make the slightest move in its direction, and it makes a beeline dart for shelter in the coral!

Fishes That Jump

Some fishes have the ability to jump or leap into the air which they exercise with various motivations; purposefully; out of well-based fear; sometimes, to their own injury, in unreasoning panic; in order to ascend waterfalls; to capture food; to dislodge fish hooks; or out of sheer playfulness. Not all fishes that jump however, do so for all these motives.

Best known among the jumpers are the salmon and trout which migrate upstream for spawning purposes, and en route often encounter rapids and waterfalls. Since they are able to jump some six or seven times their lengths, they succeed in passing over rampageous waters through which they could not possibly swim. Their leapings are not without discouragements. Often a fish will jump too vertically, and will have to make several attempts before it can continue swimming along. Sometimes one will fall back, land on a rock, and be stunned for a while, although rarely is one actually killed. Usually when a salmon—the fish most commonly seen jumping upstream—does not make the grade, it takes its setback and tries, tries again. Atlantic salmon intrepidly make such arduous journeys several times during their lives. Pacific salmon never repeat the experience, for they die soon after they have spawned.

The big sea-going lamprey eels jump too, but they have an advantage over their trout and salmon neighbors. They are able, in the very same river, to take their leaps in easy stages in a kind of natural installment plan. Their mouths are designed to create suction; with these, they cling to rocks whenever they want to halt their upstream journey to take a rest. Hundreds of these creatures have been seen snug against rock walls and rocks below or behind waterfalls. Adequately rested, they take another upward lunge of a few inches and rest again; so it goes until they are over the top.

Many of the big game fishes such as marlins, wahoos, sailfishes, tarpons and swordfishes, which sometimes ~~weigh as much as half a ton~~, jump violently to throw off hooks—and that is precisely what makes them game fish. Often they leave the water completely and thrash their heads about in their vigorous leaps. In fresh waters the smaller game fishes, the rainbow trout and black basses—large at five or six pounds (whatever you may hear about the one that got away!)—also give the sportsman a good jump for his money. The trout and the large-mouthed black bass use their jumping ability, in addition, to catch insects as food. Occasionally, the leaps of these fishes are so quick and sure that their prey is caught the instant it touches the water.

The ordinary carp jumps during the spawning season. One night when I was camping with my family in a grove of cottonwoods beside the Green River, Wyoming, I was kept awake by the continual sound of something slapping the water. About sunrise I went quietly down to the water's edge to see what was going on. It was carp, leaping out of the water and hitting its surface with their tails.

Some of the mullets, delicious as food if they are very fresh, jump in panic (Figure 8). These silvery-sided, gray-backed fishes, about a foot long, some with bright yellow spots at the bases of their fins, have fine strainer-like lips and at night swim in schools close to tropical shores to feed upon the microscopic organisms near the land. They are apparently sensitive to the slightest vibration or movement in the water, for the moment a net touches it in their vicinity they jump wildly in every direction, including the very one that makes the least sense—right into the bag of the dipnet!

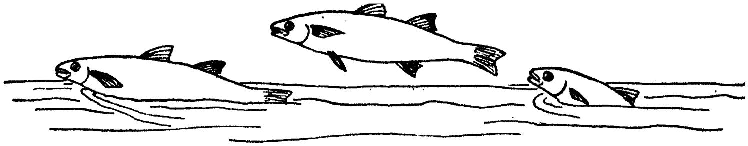

FIG. 8. When frightened, mullets ordinarily jump short distances of a yard or two. They do this with extreme speed and agility.

Jumping is so characteristic of the marine gars or needlefishes, which live in all tropical oceans, bays and river mouths, that one of them, the saltator, derives its name from the Latin word "leap." These long, slender fishes, bluish green above, somewhat silvery in the middle and underneath, slightly curve their bodies as they go gracefully over the water. It is possible that they jump because of irritating parasites, as a dog tries to rid himself of fleas, for normally they live about a foot below the surface of the sea where there are no rocks against which they can rub to scratch themselves. Like the mullets, they are certainly sensitive to danger and jump in fear or panic. Terrified adult needlefish are no fun to have about, and many a fisherman has been pierced and injured by their long beaks—one-fifth their body length, which may reach six feet, and outfitted with a set of sharp teeth.

Young needlefish, about one foot long, jump playfully like so many puppies. They have been seen gaily leaping over turtles, straws, feathers or papers floating in the water (Figure 9). Dr. Breder found that throwing a splinter of wood or a straw into a school of needlefish invariably caused at least one of them to jump over it. Sometimes a young fish would leap back and forth over the object repeatedly, although none ventured far from the body of the school for his game of leapfrog.

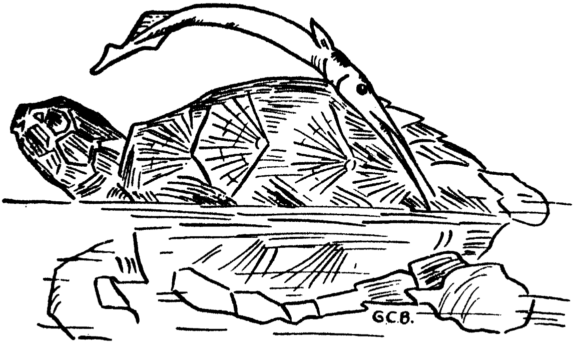

FIG. 9. The marine gar or needlefish jumping over a sea turtle. (Modified after Gudger.)

Dr. Breder made careful observations on young needlefish's play. He saw them always approach the stick or straw at right angles, stick their beaks through the surface of the water, and run them exploringly over the potential hurdle. If they found it so small that it yielded easily to their touches, or so large that it would not yield enough, they would withdraw. If its buoyancy met with their approval, violent swimming movements would follow, then the jump. Sometimes they would turn and repeat their leaping.

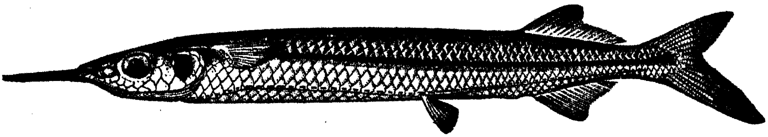

FIG. 10. The halfbeak, *Hyporhamphus,* so named because the lower jaw projects far in front of the short upper jaw, is noted for its ability to leap short distances.

The halfbeak (Figure 10), a close relative of the needlefish, resembles it, although only its lower jaw is long; the upper is tiny and short. When Dr. Breder studied the leaping habits of halfbeaks he saw them put the tips of their protruding lower jaws under a floating object and give a flip to get the leverage for the jump. Usually they landed tail first on the other side of the stick or straw, and sometimes repeated their jumps. At times a number of halfbeaks jumped in unison.

When I was in Bikini I made what are, as far as I know, the first observation of a halfbeak's flying. Twice, when I was out in a fifty-foot boat, I saw one, *Euleptorhamphus*, spread its fins and glide through the air along the entire length of the boat, so close I could almost touch it.

Here was a living illustration of the way the habit of flying developed from the habit of jumping. I had already known that the halfbeak was the true flying fish's ancestor, for some of the flying fishes have half beaks in their younger stages.

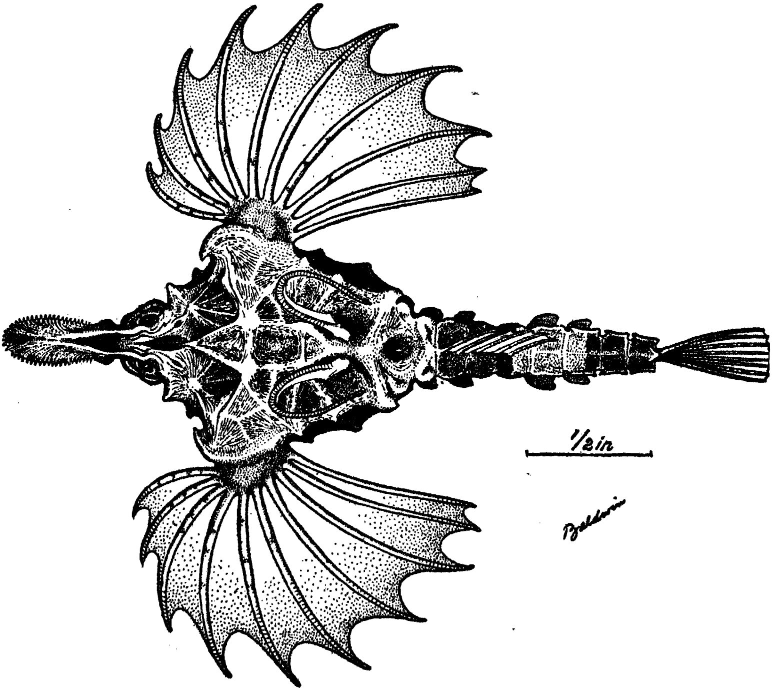

Fig. 11. The sea moth, *Pegasus*, resembles flying fishes but cannot fly. It lives in the western tropical Pacific Ocean.

Fishes That Fly

Some, but not all (Figure 11), fishes which developed a greatly enlarged pair of fins learned to fly (Figure 12). Those most highly developed and specialized are the Cypseluridae family, found in all warm sea waters. Man has developed no war machine as adaptable as they, for they are like a combination submarine and airplane.

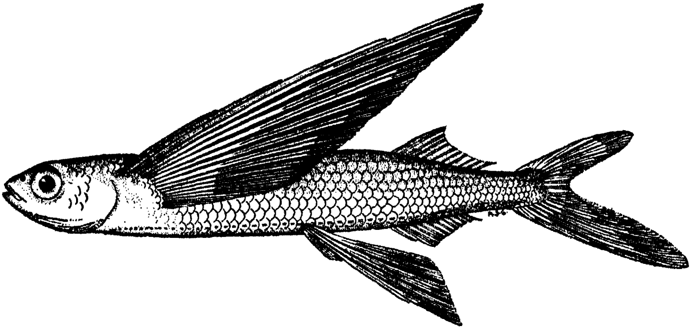

FIG. 12. The flying fish, *Cypselurus,* occurs in all tropical seas and is one of the most celebrated kinds of fishes. Its flight is a delight to all travelers of the sea.

One of the longest controversies in natural science has been centered on whether flying fishes flap their finny wings. Many writers of both scientific and so-called "scientific" literature have claimed that flying fishes use their wings for propulsion in the same way as bats do, and most of the birds. Anatomically, this is impossible, for fishes have no breast or wing muscles, like birds, that would enable them to bring their wings together before them ventrally. In my opinion the only reason there is any doubt on the matter of fin flapping in flight is because too many travelers have jumped to conclusions on the basis of their preconceptions about birds, or because they do not really understand the mechanics of flight. I am certain that flying fishes hold their wings rigid during flight. I had plenty of opportunity to make numerous careful observations of their action during the days and weeks and months I was waiting for the Operation Crossroads bomb to explode, and once a fish was aloft, never a wing motion or a flap did I see. To say that flying fishes glide through the air would be perhaps more accurate than that they fly, for one bears in mind that airplanes, too, fly with wings rigid. Indeed the design of all modern airplanes, with the exception of the helicopter, resembles that of flying fishes.

In the clear waters of the Pacific I was able to see hundreds of flying fish just before they appeared on the surface. While they were under water their wings were folded against their bodies. As they were ready to emerge, they would begin to swim with great speed in preparation for the surface taxiing which, for them as well as for planes, is necessary before they can rise into the air.

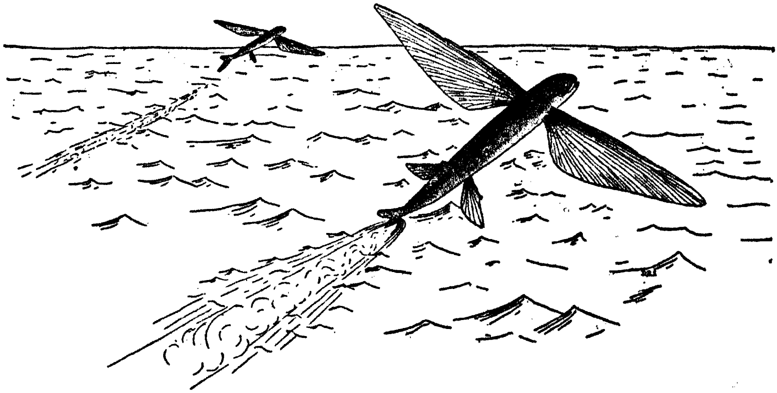

FIG. 13. The flying fish must taxi, as an aeroplane, to gain sufficient speed to lift itself into the air. This is done not by flapping its fins, but by sculling with its tailfin. Flying fishes glide like modern aeroplanes.

The moment they reached the surface they would spread their paired fins, a pair of planes with membranes taut between the fin rays, about a foot and a half across from tip to tip (Figure 13). The lower lobes of their tails are especially enlarged and strengthened to give the vigorous side-to-side swimming movement necessary for taxiing speed. When the water is not too rough the wave ring disturbances created by their motions can be clearly seen, several inches to a foot apart, tracking in their wake some thirty to forty feet. I saw the fish taxi at speeds of thirty to sixty feet per second for distances ranging from ten to fifty feet, depending upon their size—about twelve to fifteen inches long is common—, the strength of the wind, or how much they were interrupted by waves. Sometimes a fish would taxi across the crest of a wave, sail across its trough, and take up its taxiing again on the next crest. During taxiing the rigid bodies of flying fishes sway with their tail movements, and sometimes the slightly tilted, taut pectoral fins alternately strike the surface. Although these contacts are occasionally sufficiently marked to create wave rings, they cannot possibly be construed as flapping.

Rarely did I observe one of these fishes take off with the wind; the usual procedure was to head into it at an angle. Now and then I saw a fish shoot straight up from the crest of a wave, on an updraft; occasionally, too, one would fail in his attempt to rise into the air and would slide down a wave to disappear into the water.

Once aloft, flying fishes curve gradually in flight. With a stopwatch I timed hundreds of their aerial ventures. Most of them lasted from two to ten seconds. The longest single flight I have observed personally was twenty seconds, although Dr. Carl L. Hubbs, professor at Scripps Institution of Oceanography, La Jolla, California, recorded one lasting thirty seconds, and the longest on record, reported to Dr. Breder by a sea captain, is forty-two seconds. Speed in the air is about the same as speed in taxiing.

Since momentum carries these gliders only so far, if they want to cover any considerable distance above the water they must re-gather it with another taxi. I have seen fish taxi, fly, taxi and fly again in a consistent general direction as often as ten times. Th[illegible]ongest combination of taxi plus aerial gliding I timed lasted twenty-six seconds. The flights always ended with a splashing dive.

There are two general types of flying fishes: one might be called the biplane type, the other the monoplane. In the former the pelvic fins, or hind limbs attached to the underside of the body, are almost as large as the fore limbs and seem to have the function of elevating wings. In the latter the hind limbs are smaller and have little or no elevating value. Apparently they serve as lateral rudders; the tail in both types acts as the vertical rudder.

Any ocean-liner passenger who has ever rushed to the rails at the cry of "flying fish" knows that many are seen at a time. As a rule, when these fish are frightened by a ship, or are taking prolonged flights, they glide no more than two or three feet above the water, but with favorable winds they have been observed going as far as 1200 feet at a height of twenty-five feet, and in play it is not unusual for them to rise to thirty feet. The greatest flight height recorded is thirty-six feet above the surface of the water.

Although it is doubtful that flying fishes have aerial vision, they are definitely attracted by light. Sometimes at night they would fly through the open portholes of the *U.S.S. Bushnell,* the ship on which I lived in the Phoenix Islands. One flew hard into the face of a sailor who was reading a magazine. The sailor knew that I was a queer character who collected fishes, so he kindly presented me with his unintentional assailant, but the language he used in describing how he happened to have the specimen is unprintable.

From a small ship at Bikini I suspended a lighted 100-watt bulb just below the surface of the water. Within an hour and a half, with my dipnet, I had scooped thirty-six of the pretty little fishes, some with rose-colored wings, and some with translucent wings dotted with black at their posteriors. The light seemed to blind them. They paid no attention when I waved the white net through the air; indeed, if I held it quite still in the water they moved right into it. Were I to move it ever so slightly, they became panicky. Some knocked themselves out against the stern of the ship; one hit me in the shin and another plopped against the stomach of a man who was keeping me company in my ichthyological vigil. However, for all my book learning about fishes, I was no wiser than the Polynesian natives when it came to knowledge of the blinding confusion into which light throws flying fishes. Carrying flaming torches made of dried cocoanut leaves, the natives go out by night to spear and catch flying fishes as food or as bait for the sailfish, marlin and broadbilled swordfish abundant in the region.

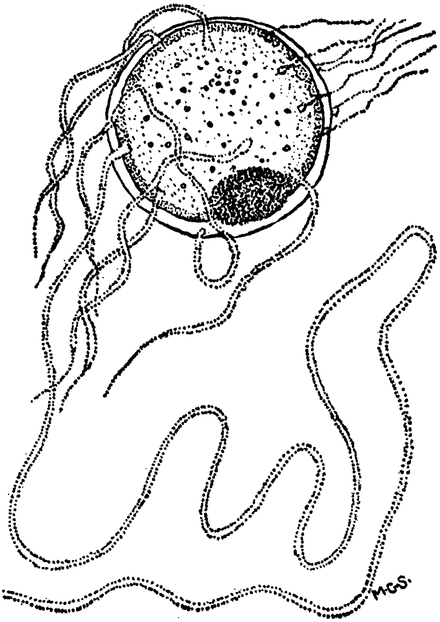

FIG. 14. This is the egg of a flying fish. The threads adhere to floating objects in the sea, such as seaweeds. At Bikini, I found a floating bottle covered with flying fish eggs. (After Nayudu.)

Off the coast of India native fishermen cleverly capitalize on another trait of the flying fishes—their habit of laying their eggs on floating objects. In waters where flying fish have been seen, they attach bundles of branches with luxuriant foliage to l[illegible]me sixty to three hundred feet long and drag them from catamarans. Shortly, forty to fifty flying fish will gather about the bundle, attractively replete with surfaces, and it is then pulled gently toward the boat. Two men haul the bundle over submerged large dipnets and the fish slide down into them when the nets are lifted from the water.

Normally flying fish lay their eggs on floating seaweed, but like home-hunting postwar Americans they are not choosey (Figure 14). Washed up onto the sand at Bikini I found a whisky bottle covered with their eggs.

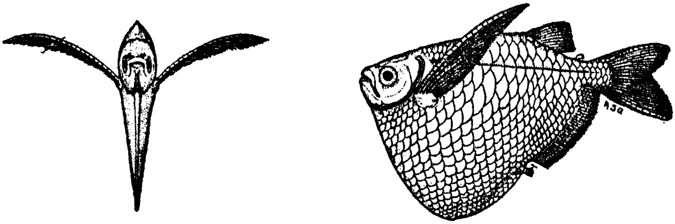

FIG. 15. This small South American fresh-water flying fish can sail for a yard or two. It is one of the characins, *Thoracocharax,* and is of interest to aquarists.

The fresh-water hatchet fish also flies (Figure 15). When I was in Venezuela I came across a stagnant pool at the bottom of a ravine. Encountering any new body of water always immediately makes me feel like a small boy who has discovered a jam jar, and so of course I dropped a seine down into it. When I had pulled the seine into shallow water about a foot deep, I noticed many fish making six- to ten-foot leaps and glides over the surface. Head on they looked V-shaped; their undersides were sharp as a knife, and just behind their heads spread out very large pectoral fins.

These fresh-water flying fish, only about three inches long with a four incher a comparative rarity, belong to the Characin family, one entirely different from that of salt-water flying fishes. They fly to escape enemies. Found in all the big river systems of South America, they make fascinating pets for aquaria amateurs, who can get them to fly by stirring up slight motions in the tank.

Obviously, birds have no monopoly on flying. Many animals have tried it through the ages; some have survived, and some have not. The *Pterodactyl,* for example, a reptile that flew, exists nowadays only as a skeleton in a natural history museum's collection of prehistoric animals. Among mammals there are the bat and the flying squirrel. But it seems to me that there is no winged creature more remarkable than the flying fish, which travels with equal grace in two elements.

A Fish That Flies and Walks

Still more versatile is the *Cephalacanthus,* one of the tropical gurnards or sea robins. Like all fishes, of course, it swims, and like the rest of the gurnards it is especially adapted for moving along the sea bottom. In addition it has been seen to spread its large pectoral fins, like the flying fishes, and to fly through the air. Flying, however, is not its *forte;* it is handicapped by its bulky shape, less streamlined than the flying fish, and by weight of its bony head and covering of heavy scales.

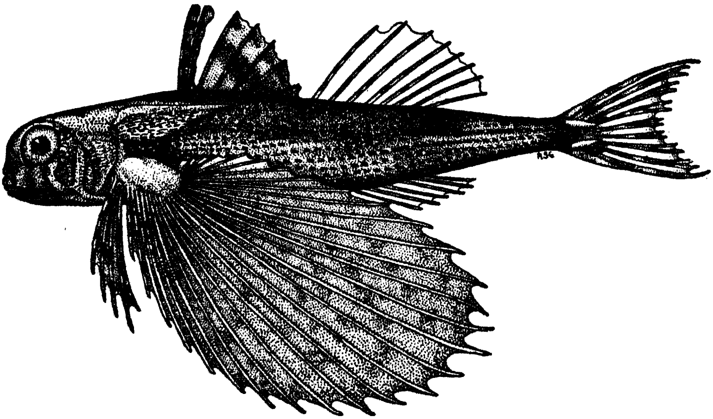

FIG. 16. The flying gurnard, *Cephalacanthus,* is really too heavy to lift itself much, if any, above the water. Close relatives, the sea robins, have the first few pectoral rays free. These are used for walking along the sea bottom.

The gurnards' outstanding specialization is their ability to move by stepping on the floor of the sea. The lower part of their sizable pectoral fins divide into three or four finger-like rays, which they use for walking as an insect uses its legs.

The curled-over tips resemble feet and serve the same purpose.

Fishes That Walk

Several other kinds of fishes walk, among them the walking gobies, blennies, certain catfishes, and serpent heads. But perhaps the most spectacular pedestrian is the walking or climbing perch.

When the crow in Walt Disney's *Dumbo* sang, "I done be about seen everything till I see an elephant fly," he failed to specify whether he had ever seen a fish walking on dry land. Yet the walking perch has been seen frequently doing just this, and by perfectly sober people.

The first recorded observation of this fish gave rise to its popular misnomer, climbing perch. About 160 years ago the Dutch naturalist, Doldorf, during a heavy rain in Tranquebar, India, observed a fish five feet above the ground on a Palmyra palm tree. It was enjoying a trickle of water that ran down the trunk. He named it the climbing perch, but today we know that the more accurate term for its movements is walking.

The walking perch lives in all kinds of quiet water such as lakes, ponds, ditches, canals and sluggish rivers in Southeastern Asia, the Philippines and the Indo-Australian region. About ten inches in length, it is built for a rugged life. Its head is blunt and very hard; its body is enclosed in a thick, tough coat covered with strong scales, overlapping like the shingles on a roof. Each of its gill covers has a spine projecting backward. Its spiny fins and armament discourage attacks of other fishes, water and land snakes, lizards and birds. Its coloring—the adults are dark brown, the young light brown with dark transverse stripes—makes it inconspicuous both in water and on land. And to give it even better protection from terrestrial animals like man, it can see them approaching, for it has aerial vision.

A supplementary breathing apparatus, situated in a cavity above the gills, enables this adaptable fish to take in oxygen direct from the air via its mouth. Its ordinary gills function like those of other fishes which take in oxygen from the water, but they are not quite adequate to sustain life and it has to rise to the surface occasionally to inhale atmospheric oxygen. If a walking perch is submerged in an aquarium closed off at the top with a wire screen, after a few hours it begins visibly to suffer. Weakly it tries to rise to the surface to get air; faster and faster its mouth opens and closes like that of a person gasping for breath, and ultimately it suffocates, or in other words drowns. However, it is one of the few aquatic creatures that can live in water rendered oxygen-deficient by decaying organic debris; so long as it is able to come up for air it can manage.

When walking perch leave the water for the land they literally step along on their fins, with the lateral movements of their tails giving motor power. Although their walking is jerky and awkward, they make up in endurance what they lack in grace. Their thick skin retards loss of moisture when they are out of the water, and as long as their accessory breathing apparatus remains damp they breathe and live. In Siam, where walking perch are abundant, they are placed alive on stone slabs at markets. Sprinkled with water periodically these fish will sometimes remain alive for as long as an entire day, in contrast to other fishes which, under similar circumstances, would expire within half an hour.

Dr. Hugh M. Smith, formerly Advisor in Fisheries to His Siamese Majesty's Government, who has furnished me with most of my information about the walking perch, has watched the travels of these fish in Siam. By night he would come upon them crossing dusty roads, dry lawns and fields. By their tracks it was easy enough to determine what water they had left, but not always possible to be sure where they were heading. Often he saw walking perch step out of waters at the foot of high steep banks and ascend them with skill and patience. They took less trouble in descents; Dr. Smith saw many a one deliberately fall or roll down a bank and land in its watery destination with a splash.

At least one walking perch, according to Dr. Smith, had a definite homing instinct. For some time he had kept it in a pond thick with aquatic plants—the equivalent of a well-stocked pantry to a walking perch. One day a servant removed the fish to transfer it in a basket to a stream, but before releasing it the servant was called away and hastily set down the basket. The fish escaped and headed back toward its comfortable pond home. During the latter half of its trek Dr. Smith had it under observation. He watched it pass through grass, over a metalled highway, between houses and through flower beds, right to the pool—a distance of about 100 yards, at ten feet per minute. Apparently it knew where it had been well off and had deliberately walked in that direction.

The answer to why walking perch in general take arduous journeys from one body of water to another must be in the unscientific class of the answer to "Why does a chicken cross the road?" Perhaps, like ambitious Americans who move from one town to another, they want to better their living conditions; they seek cleaner water or more abundant food, although often, just as the new town is merely a duplicate of the old, the pond to which they walk has no advantage over the one they have left. Then, again, perhaps they are motivated by sheer wanderlust.

Fishes That Walk and Skip

Less migratory, although great gadabouts, are certain of the salt-water blennies (Figure 17). Both the *Salarias* and the *Rupiscartes* leap and skip like lizards about the rocky shores where they live in shallow pools left by the outgoing tide.

Catching these one to five inchers hardly comes under the heading of game fishing, but it taxes all the fish collector's stock of ingenuity and patience. That they can walk away from your grasp by means of their tails and paired fins, like the walking perch, is the least of it. They can skip, too. With a flip of their powerful tails and paired fins against a rock they shoot off two or three yards at a time, so fast the eye can scarcely discern the streak.

It is almost impossible to catch one of these elusive blennies with your hands or a dipnet. They duck into crevices or press against small rocky protrusions. Using rock humps like stepping stones, they flip from one pool to another, sometimes finally disappearing into the surf perhaps fifty or more feet away.

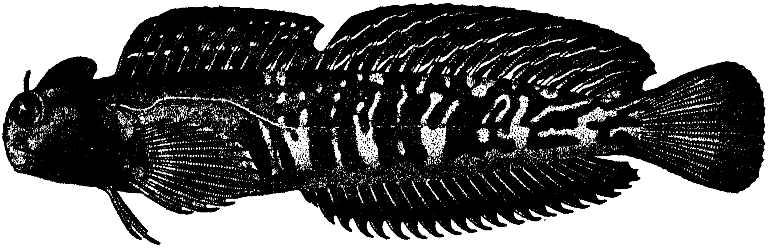

FIG. 17. Certain blennies, common on coral reefs, skip from one pool of water, remaining at low tide, to another, over the rocks.

At rest they curve their bodies slightly and tilt up their heads. Since their eyes protrude above the general level of their heads, and they have aerial vision, they can spot your approach at fifty to seventy-five feet's distance and scamper off before you have half a chance to grab them.

I have seen as many as seventy-five of these skipping blennies concentrated in one small pool, two yards wide and three or four inches deep, and considered myself lucky if I could pick up one. I have come upon thousands of them grazing—as cattle graze upon grass—on rock-covering algae (a minute form of seaweed)—light gray, whitish and bronze like their environment, but still discernible to an ichthyologist's eager eye—only to see the drab, relatively still mass burst into life and, a moment later, to stand by empty-handed and muttering. Only after I had stood patiently motionless for five or ten minutes would a few fish begin to show signs of life, walking or skipping in the air or swimming in their pool.

The *Rupiscartes* are champion climbers, sometimes ascending almost vertical walls. At low tide in Samoan waters I have with difficulty spotted these blackish fishes clambering up black lava walls to heights a few feet above my head. But being seen did not mean that they were caught. They skipped, wiggled and climbed up crevices and irregularities; now and then in his haste, one would lose its grip and tumble into the water with a splash. Occasionally I did manage to land one of these careless Alpinists by holding my dipnet under it as it fell, and closing it quickly before it could hop out; but this was a slow, hit-and-miss way of collecting my specimens.

I resorted to chemical, rather than mechanical, means of capture; unsportsmanlike, perhaps, but scientifically justifiable. I poured a poison, rotenone, into a pool, to anesthetize them; but I still had not downed my keen and active evaders, for the moment the rotenone was in the water, out they would rush. Finally I did manage to win by dipping out some of the poisoned water and throwing it upward over the fish while they were attempting to escape. Then, and only then, did the blennies perforce stay still long enough to be captured!

Fishes That Skip and Burrow

Equally agile are the skipping gobies, and their ways are extraordinary even in the strange world of fishes. Their semiterrestrial, curiously unfishlike habits indicate that they may be in process of becoming land animals; like the frogs and some salamanders who long ago came out of the waters because they found life less perilous for them on land and over the eons adapted accordingly. They may ultimately desert the sea altogether. Even today they can move more swiftly over sand or mud than they can swim, and are as successful in procuring food and escaping enemies ashore as many of their relatives are in the water.

The skipping gobies live usually among mangrove roots on the wet, mucky beaches and pool-dotted rocky ledges along the shores of tropical seas or river mouths. Though none ever wanders far from the water, some never go out to sea. During their excursions on land they have no necessity to refresh themselves with dips, for they remain healthy and active even if no part of their bodies is even damp, let alone wet. Some can remain alive out of water for an entire day. Not only are their respiratory organs and the linings of their mouth cavities modified for breathing air, but also their thick skin conserves bodily moisture, even beneath a torrid sun. Indeed these fishes seem to prefer heat and bright sunlight to chill and fog, for they do not make their appearance on land before sunrise. Once the sky is blazing, it is quite a sight—noted by the ancients as well as by modern naturalists—to see them blithely skipping about, or racing along the ground in grim pursuit of food.

Fins with an elbow-like base and strong tails adapt them especially to traveling over soft mud somewhat in the fashion that a baby creeps, although there is nothing creeping about their pace. On mud-flats they can outspeed a man walking. They scurry along, too, over sands almost too scorching for a man's bare feet.

Like the walking perch, whose eyes are best adapted to seeing under water, they have aerial vision, and one of them, the *Periophthalmus* (see around) is superendowed with it (Figure 18). With one eye it can fix its look upward—for instance, to see an approaching man—while the other scans the terrain by partially rotating, as a periscope turns in a conning tower. Its vision covers about thirty feet. Only when it comes to the sense of hearing does Nature seem to have skimped in equipping the skipping gobies for survival out of water. The sound of gun shots near enough to splatter them with mud do not seem to affect them in the least, and the assumption is that they are quite deaf to sounds transmitted through the air.

Unless they are disturbed for some reason, skipping gobies leave their pools largely to forage for the small crustaceans and insects on which they feed. When they are frightened they plunge into holes. Thus, in Siam, disappeared the largest skipping goby Dr. Smith had ever seen, and of course he wanted it. So he flaunted some bright coins before a naked half-grown native boy and induced him to go after the fish. After half an hour the boy was still throwing out mud, but the goby was not in sight.

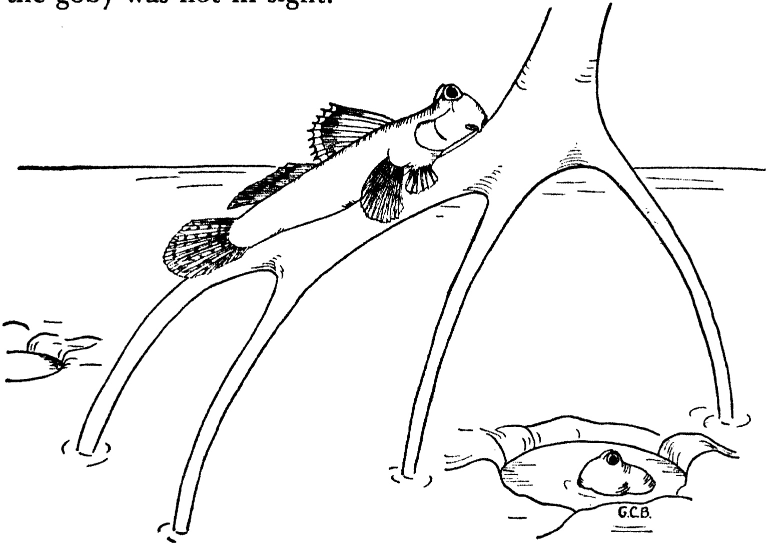

FIG. 18. The skipping goby, *Periophthalmus*, is noted for its ability to walk over mud and climb the roots of the mangrove trees. (After exhibit in U. S. National Museum.)

Gobies live in such burrows, and each individual seems to have his own, although usually the holes appear in clusters, like the units of a housing development. Probably the various burrows interconnect with tunnels; in addition to the private dwellings, there is a main burrow. This water-filled hole is surrounded by a wall about a foot in diameter, four to six inches in height, and constructed of a kind of crude, miniature brick. The gobies get the building material by wriggling down to the stiffer clay underlaying mud, biting this off, and upon their return to the surface spitting it out in the form of pellets. They are diligent masons; when a wall is damaged they attempt repairs.

The main entrance, somewhat funnel-shaped, slants downward from the pool, and is easy to locate by converging tracks of fins and tails in the mud and the furrow worn in the wall where several fish have passed. For although each dashes into its private dwelling when thoroughly frightened it makes for the main burrow when only slightly alarmed. Arriving at the wall, the goby surmounts it; then, apparently feeling safe, it rests comfortably at the top of the wall and takes a good, slow look all around before diving down into the community shelter.

Fishes That Burrow

In their habit of burrowing the skipping gobies are not unique. Some fishes burrow to find food; some, which are frail, for steady protection; others to escape enemies; still others, shy and secretive by nature, go out only at night and remain in their burrows by day. None of the burrowers is really aggressive, none tough-skinned.

Besides their common peculiarity of burrowing, several burrowers have peculiarties of their own. For example, at low tide along the North Atlantic and North Pacific coasts, clam diggers are frequently astounded to find great schools of fish apparently buried alive in sand, six to twelve inches below the surface. These are sand launces, and it is as much in their nature to burrow through loose sand or gravel and repose snugly below as it is for them to swim.

Rays, skates and flounders also have a way of wriggling down and completely concealing themselves in sand. These flatfishes, like chameleons, change their coloring to match their environment.

The burrower *Trichodon* (hair tooth) which lives on the Northern Pacific coast of North America is noteworthy for its fringe of super-fine teeth, which strains water that otherwise would be chokingly full of sand and gravel.

Exquisitely delicate, the translucent, milky-colored *Chalixodytes* (sand diver), only one and a half to two inches long (Figure 19), spend most of their lives in the sandy bottoms of tropical waters. The only place anyone has managed to catch one is in loose sand in the shallow waters between coral heads where strong currents and waves roil the bottom.

In the temperate and sub-Arctic zones of both hemispheres the young of the lamprey, a fresh-water fish, have a name of their own, ammocoetes, and ways unlike those of their parents. Almost immediately after they are born, they burrow down head first into the mud floor of streams, make a U-turn and come up with their heads at the surface of the bottom. For two or three years before they change into adults, as polywogs change into frogs, and caterpillars into butterflies, they are blind, and contentedly lead quiet mud-bound lives, occasionally making new burrows, feeding upon debris that floats by.

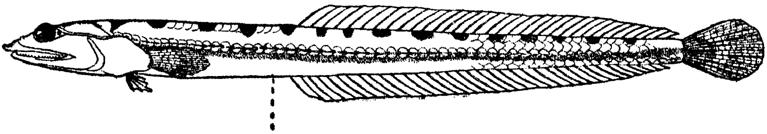

FIG. 19. The sand diver, *Chalixodytes,* of coral atolls of the tropical Pacific Ocean. (After Schultz.)

When it comes to speed and agility the tropical snake eels are the outstanding burrowers. These elongated fishes, sometimes no thicker than a man's thumb yet two and a half feet long, go down tail first to a depth of three feet in loose gravel or sand. So fast do they travel that no digging with a shovel can keep up with them, and since they swim usually at night, about the only way they can be collected in quantity is by use of poison. The smaller worm eels have similar habits and burrow almost as fast.

There are fishes which really dig in when they burrow and remain in their holes for a considerable period. For some fishes, like some mammals, are seasonally dormant and go into a kind of prolonged sleep when climatic conditions are unfavorable to their survival.

3

HIBERNATION AND ESTIVATION

How Fishes Hibernate (Pass the Winter in Torpor)

ONE of the most frequent inquiries I receive at my office runs something like this: "I was cutting ice and I found a fish frozen solid in one of the cakes. I put the cake of ice in a tub of water and when it thawed the fish started to swim. Does this mean that a fish can stand freezing?"

The answer is that the water—not the fish—was frozen. A fresh-water fish freezes at a temperature a little lower than the freezing point of fresh water, so it can be in ice yet not be frozen. Actually, any fish found "frozen solid," and yet will revive, is hibernating in ice, as bears hibernate in trees, woodchucks and ground squirrels in burrows, and some amphibians under leaves.

The hibernation or long winter sleep of fishes is common in the temperate zones, and an account of it was given by a Greek, Theophrastus, as long ago as the third century B.C. Anyone who has observed carp even casually knows that when winter sets in whole schools of them retire to the bottom of lakes or ponds and spend months dormant and partially buried in mud.

Unlike the temperature of warm-blooded animals, which rises or falls only because of changes in the physiological conditions of the animals and normally is uninfluenced by external heat or cold, the temperature of cold-blooded animals, among these the fishes, adjusts to match the temperature of the water in which they live. Dr. P. J. Schmidt, a Russian ichthyologist, conducted experiments with common carp to find out how cold they could become and still survive. Under carefully controlled conditions, he periodically lowered the temperature of the water in which the carp were kept and at each stage of chilling took their temperature by inserting an electrical thermometer into their bodies. Not until their body temperature had gone down to nearly minus one degree Centigrade (30.2° Fahrenheit) did they freeze to death.

At zero degree Centigrade (32° Fahrenheit), the point at which water freezes, a fish may appear dead, for its respiratory movements cease and it is in a state of torpor; but experiments have shown that fish kept under these conditions for as long as ten days at a time revive quickly when the water temperature is raised. Empirically, we are justified in assuming that dormant fishes under natural conditions stay equally healthy throughout whole long cold winters.

When a fish is hibernating its metabolism sinks so low that it can live on stored energy and does not need to eat to maintain life processes. The one hazard to which it might succumb would be lack of the oxygen it must absorb. So a marvelous correlation of the behavior of water and the behavior of fishes brings about an adequate supply of the precious, vital element where and while it is needed.

Water in ponds and lakes is stratified. During the summer months the upper layers are well aerated and hence ogygenated, thanks to continual stirring-up by wind, while at the same time the lower layers become depleted of oxygen by the decomposing organic matter that gradually settles down into them. In the autumn, when the temperature of surface water goes down to four degrees Centigrade (39.2° Fahrenheit), the point at which water is heaviest, this upper layer, rich in oxygen, sinks to the bottom and replaces the warmer, lighter, impoverished layer, which rises to the top. Since the fish have fled from the uncomfortable and enfeebling chill of the upper waters, and hibernate far down, the water around them has an ample store to supply their modest winter oxygen needs.

In rivers, which always have water flowing under the ice, there is plenty of oxygen and river fishes merely retreat to the deeper holes where they may remain in a semi-torpid state.

But even under solid ice in lakes and ponds not all fishes are completely inactive. Some move about, although not so energetically as in warmer weather. As the deep-sleeping hibernators owe their lives to the shift in layers of water, so do these almost fully functioning fishes owe their activity. As winter wears on and water becomes colder than four degrees Centigrade, it becomes lighter too; therefore the coldest water, which turns into ice, floats, while underneath is a layer of heavier water, warm enough not to prevent all normal activity. Thus again the laws of physics and of zoology beautifully dovetail.

Long before I had acquired any scientific techniques of fish collecting, I learned from Michigan farmers how to catch the fishes awake under frozen surfaces. First you make holes in the ice. Then, through these holes you drop corn or anything else light colored that settles to the bottom, so that when fishes swim over it they will stand out against the pale background and not be invisible, dark against dark-colored bottom. Next, as people tap on pet-shop windows to goad puppies into motion, you tap upon the ice near the holes to drive fish to swim across. When a fish appears in the opening you spear it!

The genuine hibernators, however, are safe from man's trickery. In small lakes or ponds where long winters reduce practically the whole body of water to the freezing point, they lie peaceful and oblivious in their long sleep, like so many Sleeping Beauties who will be awakened by the kiss of Spring.

Fishes That Estivate (Spend The Dry Season in Torpor)

Certain fishes living in tropical regions need habits that will enable them to survive not cold but drought, and these are dormant during the rainless months.

Among them is *Pseudapocryptes,* one of the gobies, common in the delta of the Ganges River of India. It has the relatively uncommon habit of burrowing for a special seasonal purpose. This goby, like its skipping relatives, wiggles head down into the soft mud of shallow pools, to open up vertical or slanting holes. En route, its mouth naturally becomes filled with mud; it gets rid of this by shooting it in clouds out through its gill covers, as a smoker blows out through his nose the smoke he has taken in his mouth. By the time the fish has burrowed down about a foot, the clouds have settled around the opening of the burrow and it acquires a crater-like look.

When these gobies reach hard clay, again like their relatives, they bite off and eject it in little lumps. With these pellets they proceed to line their burrows, and as they pass in and out of them the slime that oozes from their bodies supplies a smooth inner coating.

The *Pseudapocryptes* is busiest with its construction work during the rainy season, especially at night, when it is dampest. During February and March, the dry season when the waters are low it settles down for a well-earned rest and, tail down, lies dormant in its burrow. Fortunately it is adapted for breathing air. As the water recedes, its head and much —often most—of its body is out of water. Specimens taken from a depth of six feet had only their tails touching a bit of slimy water at the bottom of their burrows.

Plunged into water this fish begins slowly to breathe and to revive almost immediately. Under natural conditions it again becomes active when the water in the burrow reaches its head, a matter of many weeks. This long-term ability of a fish out of water to maintain life may be astonishing; but even *Pseudapocryptes'* strange ways seem ordinary in comparison with those of some other estivators, the lung fishes.

When I see one of these velvety skinned animals, about three feet long, grayish-green above and on their sides, lighter underneath, I get the same thrill as a bibliophile when he comes upon some rare old volume. For they have the fascination both of antiquity and scarcity; they are one of the oldest air-breathing vertebrate forms still living on this earth. Once, in the waters of paleozooic land masses, they were abundant in both kinds and numbers. Today, only remnants of this great lung fish population remain. There are only three kinds: *Neoceratodus* the largest, in Australia (Figure 20); *Protopterus* in the Gambia and Congo rivers and lakes of equatorial Africa; and *Lepidosiren,* or mud siren, in the Amazon and Paraguay River systems of South America.

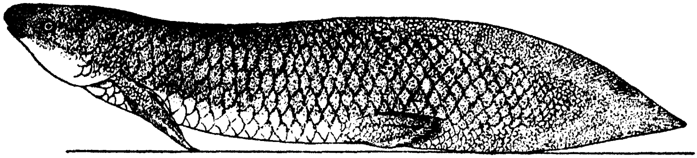

FIG. 20. The Australian lungfish, *Neoceratodus.* (After Dean.)

Sometimes, eons ago, the lung fishes and the land vertebrates had a common ancestor. Then, just as man and the apes descended along different lines from an extinct forebear who was neither, one line developed into amphibians while the other remained definitely fishes, albeit with some unfishlike traits.

For the lung fishes, as their name indicates, are equipped with full-fledged lungs as well as with gills like the rest of the fishes, and at intervals must rise to the surface to breathe air. Still they are fishes and need water too; so when the swamps or pools on whose bottoms they live dry up, they estivate, buried in burrows in mud.

They are sluggish creatures who habitually move slowly and deliberately. Their vision is poor; their habits are nocturnal. In some ways they suggest the salamander, or mud puppy. Like it, they raise themselves on their pectoral appendages and pose for a while; then they move their necks sideways more in amphibian than in fish fashion.

In swimming they undulate their whole bodies. When they are alarmed, and swim relatively fast by means of strong tail movements, their pectoral fins flutter while all the other fins are folded tight against their bodies. In slow locomotion they use their pectoral appendages for balancing, sometimes moving them alternatively, more often in unison—again salamander-like (Figure 21).

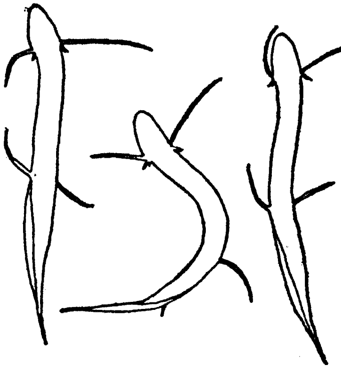

FIG. 21. Swimming movements of the African lungfish, *Protopterus*. (After Dean.)

Further evidence for their collateral kinship with the amphibians lies in their feeding habits. Cocking their heads as if they were nearsighted, they snap at their food. It is a pathetic sight to see how clumsily, with how much difficulty, lung fishes obtain their food. Their eyesight is so poor that some tempting morsel, the living or dead animal matter or aquatic plants they eat, may be right before their noses before they are aware of it. After a while the stimulation of their taste buds and the sense of smell lead them to move in the direction of the food and blunderingly they snap at it. Sometimes they miss their aim and not until after several attempts do the tidbits land in their mouths. Withal, these animals do not die untimely of starvation or frustration. Specimens in aquaria have lived for more than fifteen years, and their size and rate of growth while there showed that some of them must have spent at least ten years fending for themselves before captivity.

Lung fishes' breathing movements ordinarily occur about twelve times per minute, and when they are excited up to thirty times. In ordinary respiration most of the water they breathe goes in through their nostrils—a most unfishlike place of entry—and only a little into their mouths and out through their gills. As water temperature is raised they breathe faster and open their mouths wider, like panting dogs. They can live in water as hot as one hundred degrees Fahrenheit and almost devoid of oxygen; but deprived of air, like the walking perch, they drown. Regularly, when not torpid they have to rise to the surface every forty to sixty minutes and, if they are excited, oftener. When a lung fish is in need of air it shows uneasiness by gasping, moving its head and twitching its fins. It rises to the surface to gulp in air and exhale several times. Then, refreshed, it closes its mouth and with bubbles passing out through its gills, sinks again to its home on the bottom.

During estivation these fishes are as snug as the proverbial bug in a rug. So profound is their sleep that they can be handled without awakening; and so tightly do they fit, coiled belly-side down, into the chamber at the end of their burrow there is not even room for the waste products of their bodies. Since they do not eat during dormancy no faeces develop, but urea does accumulate in their blood and tissues. Dr. Homer W. Smith found that it takes from fifteen to twenty days after the *Protopterus* has awakened from its long sleep for its body fully to be rid of this waste product. If plunged into water during estivation, however, lung fishes revive almost immediately.

As the water diminishes during the dry season *Protopterus* burrows deeper and deeper until finally it is forced to take its seasonal sleep. Thereupon it coils up in its chamber, or cocoon, with its mouth at the entrance. Through its lips it extrudes mucous, which, like a kind of elongated bubble gum, shapes into a tube. With all the rest of the burrow's entrance sealed with mud, this tube provides the lifeline to the air, which goes in with the creature's inhaling much as liquids are sucked in through a drinking straw.

Mucous, which soon dries stiff, also lines the inside walls of the burrow. The *Protopterus* lies quiet and packaged, as if it were breakfast food wrapped in waxed paper, until rising water reaches its cocoon, softens the earth and turns the brittle mucous wall papering and tube into the texture of wet paper. Soon the fish begins to stir; then, after an overture of grunts and croaks—another reminder of the lung fishes' common ancestry with the amphibians—it swims briskly off.

A ventilated home for the dry season is not the only construction work performed by the *Protopterus.* Shortly after the rainy season they make nests for their young. In shallow water they make special burrows into which both males and females put leaves and sticks, and here the eggs are laid. At this point the female has done her duty by the coming generation; it is the male who stays in the nest for the eight days before the eggs hatch, and for the twelve days thereafter until the larvae are old enough to leave it. From time to time he moves his fins vigorously, probably to oxygenate the water.

The larvae have four pairs of plume-like external gills through which they respire in the same way as salamanders and tadpoles. They are also equipped with ventral suckers and by means of these they attach their undersides to rootlets in the burrow. Like their parents, the larvae are most active at night.

The *Lepidosiren's* nesting habits resemble those of the *Protopterus.* Living in papyrus meadows in partially dried up ponds, channels and sloughs, sometimes only a few feet wide and deep, or in swamps where the bulrushes rise higher than a man's head, the South American member of the lung fish family burrows in the muddy bottoms and fills its nests with leaves and grass. The end of the burrow is enlarged, and there the male coils while he is on guard. The eggs, like those of frogs and salamanders, are surrounded by a gelatinous substance, still another reminder of that extinct common ancestor of amphibians and lung-fishes. In the fish line of descent, this coating is much thinner and disintegrates much sooner after hatching than in the amphibian.

The burrows the *Lepidosiren* make for estivation are distinct from their nests and the two are often some distance away from each other. Of all the bedchambers of estivating fishes, these and the hall ways that lead to them are the most elaborately designed and constructed. The entrance, about two and a half inches in diameter, is hardly visible from the outside, shows only in the clay convex plug that keeps out weeds and grass (Figure 22). This stopper is not airtight; it is composed of several pieces of clay loosely enough fitted to permit three or four airholes one-quarter to three-quarters of an inch in diameter. Adjacent to a plugged burrow, there is often another connecting one which indicates that the mud siren used a supplementary entrance while it was at work. Before it retires for the drought this engineering aid is plugged, too. All the entrance plugs are manufactured of surface clay and are therefore inconspicuous because they blend with the surrounding clay; instinctively the *Lepidosiren* seems to realize that making them of lighter clay brought up from below would be equivalent to "X marks the spot."

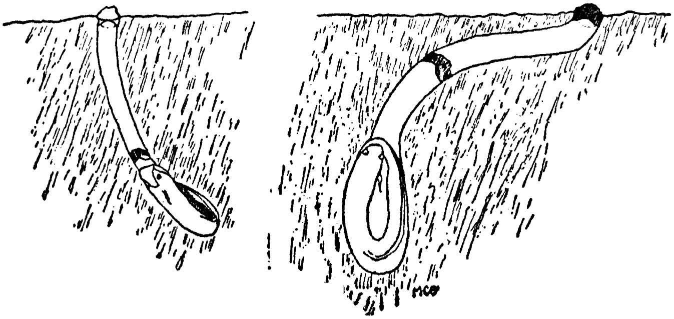

FIG. 22. The South American lungfish, *Lepidosiren,* estivating in its burrow during the dry season. (After Kerr.)

Invariably the mud sirens build their burrows in the lowest part of the pond or channel floor, because when the rains fall again this area will be the first to be filled with water and the fish can awaken from their long sleep at the earliest possible moment, push out their plugs, and once more take up active life.

This fish's mucous-lined tunnels, two and a half to three inches in diameter, penetrate the mud from one to three feet. The longer tunnels are plugged not only at the entrance, but also every four to six inches. An English zoologist, Dr. J. Graham Kerr, counted five plugs in some tunnels, the last of the interior plugs some twenty inches from the surface and almost touching the dormant fish. In one burrow Dr. Kerr examined, the lowest plug had not quite been completed; perhaps the *Lepidosiren* had fallen asleep on the job.

Down at the end of the tunnel, where the moisture and dampness are greatest, is a gourd-shaped chamber about fourteen inches long, six inches wide at one end and three or four at the other, and usually one-third filled with water. Dr. Kerr found such cocoons to be lined with a gelatinous substance, which, he discovered, with the scientist's lack of squeamishness when he is seeking knowledge, was tasteless. Although all the specimens that Dr. Kerr removed from cocoons were full grown, the Indians who helped him to locate them assured him that the young estivate similarly.

The impervious nature of the clay in which the South American lung fish burrow is important for their survival; if their skins dry out they die within a few hours, and they might not be able to live through estivation in a medium less fitted for conserving their water supply. So moist is it where they sleep that the substance with which they surround themselves remains soft, while their African relatives have to make up for the amount of evaporation in their bedchambers by wrapping themselves in their equivalent of waxpaper.

During occasional rainy years, when the waters in which the mud siren lives do not dry up, they do not estivate for they burrow only when they must. The local Indians prefer to have them dig in. Then, just before the fish are torpid, they thrust sticks into the burrows and hence into the fish's mouths. The fish seize the sticks and are pulled out.

Sometimes estivating fishes are caught less deliberately. One day, at a meeting of the Linnaean Society of New South Wales, a Mr. Fletcher produced some specimens of *Galaxias,* a south temperate relative of whitefish and of trout. They had been found dormant and enveloped in a thin veil of mucous, during some digging for drains and postholes at West Strahan, Tasmania. As far as I know, no one has studied the estivation habits of these Galaxids; they are part of the unfinished business of ichthyology.

We do, however, know much—sometimes, at a cost of suffering and death—about fishes dangerous to man.

4

FISHES DANGEROUS TO MAN

PARADOXICALLY, one of the most formidable venomous fishes in the world is not belligerent. The stingray does not even use its redoubtable armament of poisoned barbs to kill its food, and it never takes the initiative in attack. Everything about this fish—its peculiar stinging apparatus, its color, its manner of swimming—is organized for self-protection, for defense, not offense. But that does not make it any the less dangerous. It will sting to wound or kill at the slightest provocation (Figure 23).

There are several dozen different kinds of stingrays found in all tropical seas and in some South American fresh waters. The lake and river species, about one foot across, are babies compared to their marine relatives; the giant "stingaree" of Australia is over fourteen feet long and weighs at least 750 pounds. Captain Cook caught several of these big rays when he made his voyage in the *Endeavor* in 1770, and called the bay where he found them, Stingray Bay, now Botany Bay. Other marine stingrays five and six feet long are not uncommon, and their footlong stings have frequently been found imbedded in captured sharks. I myself found two in the flesh of a thirteen-foot eleven-inch 800-pounder I dissected at Bikini.

Men whose hands have come in the way of these stings, with prompt treatment have survived, but have suffered immediate pain and deep wounds on thumb or palm severe enough to cause fainting. Other men have died in agony from the poison that entered their veins.

Related to the more publicized shark family, both marine and fresh-water stingrays are flat, disk-shaped fishes, usually with long tails that are sometimes whip-like, and with one or two spines attached to the upper middle parts. Visibly and invisibly these spines are equipped with devices perilous for the unfortunate human or animal who jostles or otherwise disturbs the fish that bear them. Along their sides are dozens upon dozens of tiny barbs hooked backwards; these catch on muscles or flesh like so many sharp fishhooks. Along their bases are glands whose little ducts eject, along the barbs and

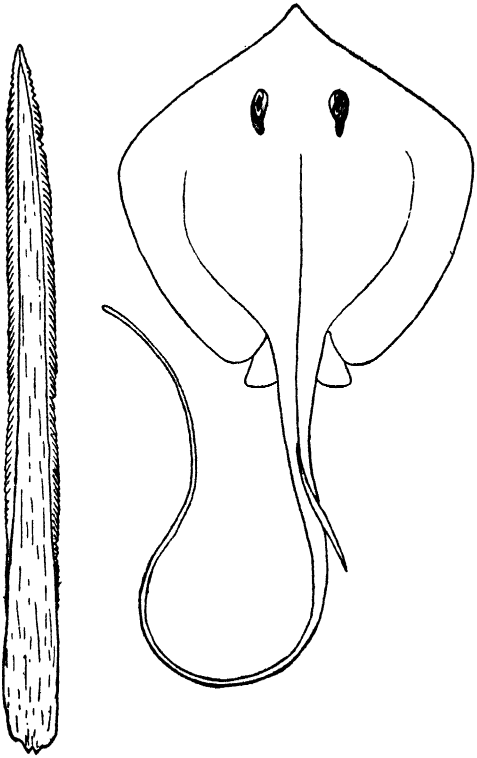

FIG. 23. The stingray, with the venomous spine on its tail, is one of the fishes that must be avoided by waders. The sting, with barbed edges, has poison glands along the bases of the barbs. Stingrays, found along seashores and in bays of tropical seas, are very prevalent in the rivers of South America.

thence into the wounded victim, a virulent poison similar to the venom of snakes.

If the stingray's weapon is damaged it eventually comes loose at the base and a new one grows for further use. If it breaks off and stays with the victim it cannot be pulled out because of the hooked barbs, and must be either pushed through lacerated flesh or that flesh must be cut away around it.

Many are the recorded tales of stingray casualties. A young man became extremely pale and fell down almost senseless for a few minutes, after having received only a very small puncture. In British Guiana, a colonist died in violent convulsions and the two Indians who accompanied him were wounded in the feet and fell seriously ill; they recovered the use of their feet only after a long period of suffering. Near the China coast, a young man fainted and, on regaining consciousness, was numb and paralyzed in the stung limb. On the Upper Amazon a Peruvian, Fabriciano Vela, was stung in the sole of his right foot while wading, and despite valiant efforts to control himself, wept, and holding the wounded foot in both hands, writhed in agony; not for several hours did his unendurable pain subside sufficiently for him to remain quiet. Friends of mine have been among the injured.

But the knowledge that stingrays were abundant in the Cienaga Guanavana, a Venezuelan swamp stretching for miles parallel to the Gulf of Venezuela, did not keep me away from it. The region has nothing to appeal to a tourist; it consists of a shallow, muddy, mucky mire, with bulrushes growing above a tall man's head and there is the constant hot, humid breath of trade winds. For an ardent fish collector, however, it has great attractions: during dry seasons, when its two or three feet of water becomes concentrated, specimens are abundant.

When my assistant, Ramon Navarro, and I came to one of the deeper parts of the swamp, where Goajira Indians live in stilt houses built over the water, we hailed a boy to come over with a *cayuca* (wooden dugout canoe). We reached a place where the water was so shallow we could not paddle, so the boy, Navarro and I walked, pushing the *cayuca.* There was mud halfway up to our knees; it stuck to our shoes, and we had to take them off.

I was not worried about the boy's taking care of himself, because I knew he would be as familiar with stingrays as an American boy would be with stinging jellyfish. But I warned Navarro very literally to watch his step. "Be sure not to pick up your feet," I said, "shove them along in the mud." I explained why. Stingrays live in muddy or sandy bottoms, feeding upon, mouthing and crushing with their teeth the shellfish and worms clustered there. When resting they lie partially buried in a surface layer of sand and mud. If you step on a stingray and press it down deeper, that gives it the leverage to throw up its tail, vigorously erect its stinging spine and stab it into your flesh—an inch or more, in the case of the Venezuelan fish on whose domain we were trespassing.

From time to time I could see clouds of mud stirred up by something swimming swiftly away, and recognized the trail of stingrays by the mud turned up in curls at regular intervals by the fish's undulating motion. Almost indistinguishable from the mud or sand in which they live, colored brownish with some spots, stingrays are not easy to see, especially because they always travel alone, not in schools like sardines, herrings or some minnows.

Perhaps Navarro, unlike the Indian boy tutored by experience, or me, by book and laboratory learning, got a false sense of security. At any rate, after a while he forgot to shove his feet, stepped as if no poisonously alerted creature sporadically carpeted the swamp. Suddenly writhing, he cried out in agony. A stingray had driven its spine into his ankle. The boy and I half lifted, half shoved him, groaning and panicky, into the cayuca and made him stay there until we pushed it to shore. There I examined the wound. Fortunately the spine had not broken off, but the wound went down to the bone. I applied first aid, disinfecting the wound. Poor Navarro complained that the treatment hurt as badly as the sting, but a week later I had the satisfaction of seeing the wound healed clean.

Even after that experience, horrible albeit vicarious, I cannot really hold a grudge against stingrays. Like the peaceful nations, they do not use their offensive materials unless they are trod upon or invaded; they ask only to be left alone.

Indeed, all the fishes equipped with poison glands whose hurtful products shoots out through grooved spines, effective as a hypodermic needle, sting only when they are touched. There are a number of them, members of several families, and in the course of my adventures and explorations I have had personal experience with too many!

My first wound from a stinging fish came in a country no more exotic than the United States of America. One summer about twenty years ago, while I was seining in the Mississippi River, I pulled up a seine-full of aquatic plants and many fishes which flapped about and squirmed. I noticed a few fish, black in color and only two or three inches long, conspicuous for their stillness. I should have known better than to make a careless grab for one of them, for I recognized them as mad toms, a small species of catfish occurring throughout the Mississippi Basin and in weedy places in rivers of the Atlantic slope. I knew that they stung. But partly because my relationship with the little creatures had previously been amiable and I had safely picked many a one up, and partly because my collector's zeal got the better of me, I thrust my hand into the seine and willy-nilly closed it over a mad tom. Into my finger it promptly jabbed one of the spines attached to its pectoral fins, and the pain shot up my arm all the way to the shoulder. Since that experience I had rather be stung by a bee than by a mad tom. Both on occasion have injected their poison into me, and here is one aspect of animal life in which I prefer the insect to the fish!

Mad toms have catfish relatives all over the world, in seas and in fresh waters. Many of them also have stinging spines, some on their dorsal as well as their pectoral fins. I ran across one of the troublesome catfishes in South America.

The *Pimelodella,* a little larger than its North American relative, has even more wallop in its sting, which hurts excruciatingly for a short while. After invading its domain in fresh-water streams and suffering from its stings almost daily for several weeks, I must have developed an immunity to its poison, for although I continued to be stung just as often, I had no greater discomfort than from so many mosquito bites.

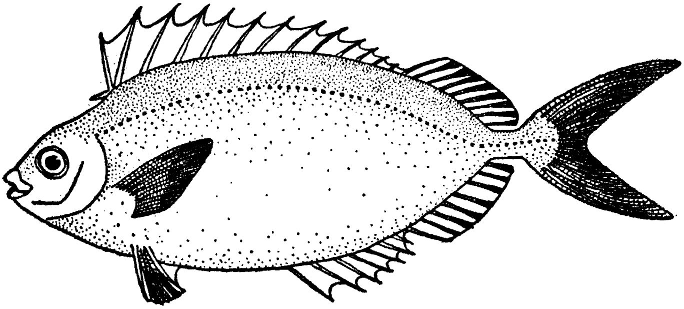

FIG. 24. *Siganus,* the only genus of fishes with two strong spines in each pelvic fin, is also venomous. The poisonous and grooved pelvic spines caused me much pain at various times at Bikini.

I have had my share of painful wounds, too, in the South Pacific. In 1939 I inadvertently jostled one of the siganids (Figure 24), the only family of perch-like fish which has two stinging spines on each pelvic fin. The ensuing pain was mild, for some reason or other, to what I experienced many times over from other siganids when I was at Bikini during Operation Crossroads.

Fortunately the poison of the siganids absorbs within an hour. But the venom of some other stinging fishes has a reaction something like that of cobras and rattlesnakes. The weavers, most often reported in the Mediterranean, and the South Pacific scaleless toadfishes—which do not look like toads—have caused their share of pain and illness. Dr. Theodore Gill, nineteenth-century Smithsonian ichthyologist, stated that the slightest pressure on the base of one of the spines protruding from the dorsal fins near the head of a toadfish (Figure 25), causes a jet of poison to spurt a foot or more from the end of the spine. When this enters a human being, pain and fever follow.

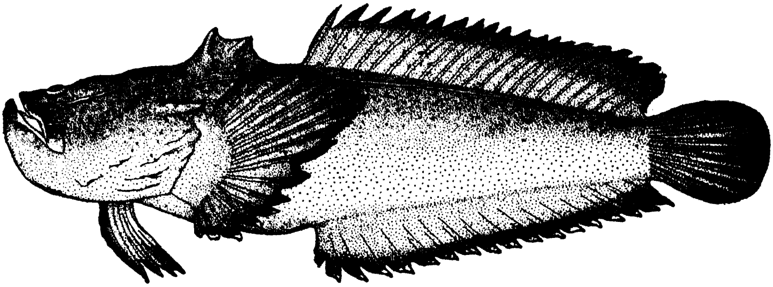

FIG. 25. The toadfish, *Thalasophryne,* is said to be the most venomous of all fishes, yet the stonefish is a close runner-up.

The variety in appearance of certain fishes, all armed with poison-conducting spines and all living in the same areas in the South Pacific, is amazing, for it runs the gamut from the hideous to the beautiful. In the case of the scorpion fishes it is hard to believe that fever and death lurk behind such

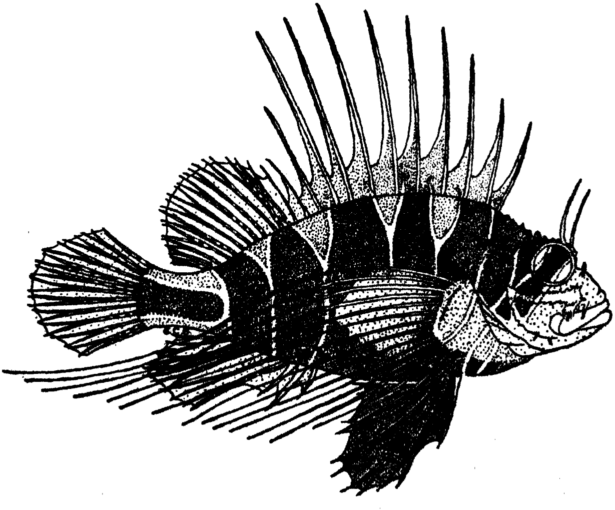

FIG. 26. One of the most gorgeously colored poisonous fishes is *Pterois,* the tiger fish—so named because of the black stripes.

gorgeousness. Some have plume-like fins even more lacy and delicate than those of fancy gold fish (Figure 26). A few species display a flamboyant pattern of black and yellow, red and black, and red and yellow, juxtaposed against a pastel background of exquisite reds and oranges and oranges and yellow, shading and blending subtly one into the other.

Another striking beauty, and close relative of the scorpion fishes, is the tiger fish or zebra fish, named for its bold yellow and black stripes. This handsome little menace has a series of spines on its head and dorsal and pectoral fins, and even a prick from them is very painful. While I was at American Samoa I heard of a little Polynesian boy who had recently been killed by a tiger fish. He had reached his hand under a rock slab on a coral reef and had been stung badly. The arm swelled immediately; the pain was intense. A few days after the mishap the wretched youngster died.

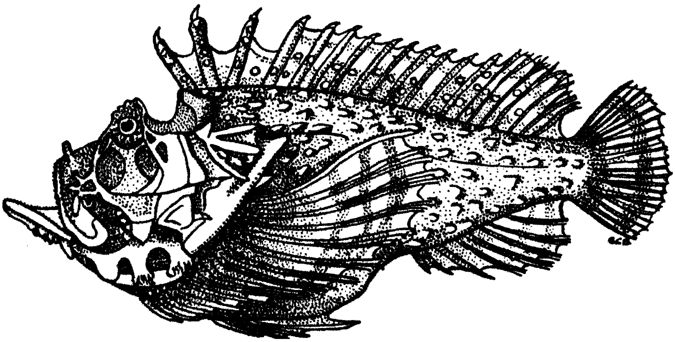

FIG. 27. The stonefish, *Scyanceja,* of the tropical western Pacific and Indian Oceans, is one of the most dangerous of the venomous fishes. By its camouflage coloration it resembles exactly the coral reefs on which it lives. To step on it is to meet disaster. (Modified after Bleeker.)

Were it not for the stonefish a moralist might be inclined to generalize on the perils hidden behind beauty (Figure 27). But this stinging fish is ugly as its lethal power. It has a bulldog like head covered with spines, and dorsal fins made up of short, stout spines based in poison glands. Dull colored, it is so camouflaged that it is almost indiscernible against the bottom where it lives, ready to give its full battery of poison from its dozens of spines to any one wading on the coral reefs. The South Sea islanders have a grim respect for this fish. When I was at Pago Pago several Samoans warned me to be sure never to step on it, and one man even went to the trouble of catching a stonefish to show me what it looked like. I knew what it looked like and I should have deeply regretted the risk the fellow had taken. But I am incorrigible. I was delighted to have the specimen!

Fishes That Attack Man

Temperamentally quite different from the stinging fishes is the piranha or caribe, which attacks out of sheer bloodlust. This savage little killer, usually only eight to twelve inches long, is vicious out of all proportion to its size and, unlike sharks, which ordinarily attack only animals smaller than themselves, seems to be utterly fearless. In writings for the general public as well as in scientific papers, the nature of this fish has received attention. Dr. R. L. Ditmars, in his *Strange Animals I Have Known,* said it "would make a ferocious wildcat seem tame by comparison." Theodore Roosevelt called it "the most ferocious fish in the world." In at least two detective stories a piranha has been the instrument of murder.

The piranha infests fresh waters of eastern and central South America—lakes and ponds, and the streams and pools from the Amazon to the Orinoco (Figure 28). Residents of the region are well aware of the scourge and take pains to bathe only where they are sure there are no piranha, or in groups that keep constantly splashing the water.

While the appearance of these fishes is somewhat sinister it is not nearly so horrific as their behavior. In coloring some species are brown- or black-spotted on silvery grayish backgrounds; others all gray above, and whitish, yellowish or pinkish below. In shape they resemble the North American sunfish, flat and deep-bellied. Along their ventral surfaces is a series of spiny, sharp-edged scales but not with these do they do their deadly work. Their weapons are triangular teeth which, above an undershot jaw, close over each other like the blades of pruning shears and are so sharp that Indians of Guiana use them mounted as knives or arrow points.

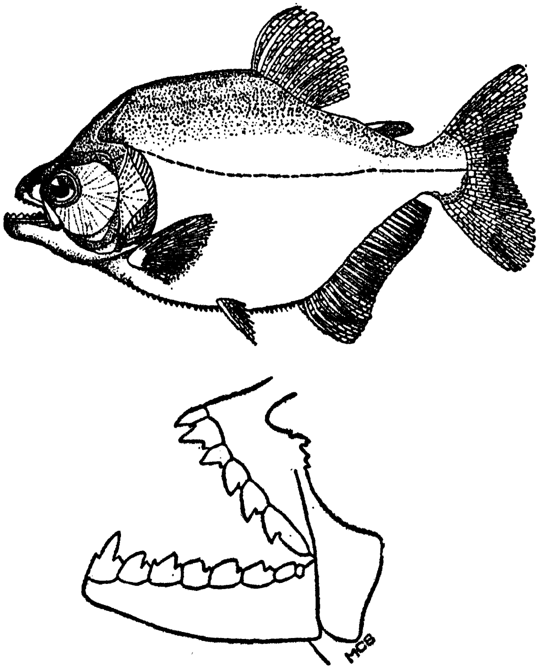

FIG. 28. The piranha of the Amazon and Orinoco Rivers of South America is one of the most bloodthirsty fishes of the world.

Habitually bloodthirsty, the piranha attacks man and beast without provocation. One bite by one piranha and off comes a chunk of flesh. Luckless fishermen, trailing their hands in the water, have lost fingers; women pounding their washing near the shore have lost toes. A party of explorers dynamited a stream and when some of the fish settled to the bottom a good diver went after them. Taking a stunned fish in each hand, he held the head of a third with his teeth. Just before he reached shore the fish recovered—and snapped off a section of his tongue. How many fledglings have been eaten in one gulp, how many sizable swimming birds have lost feet to rapacious piranha, nobody knows.

One bite by one piranha is a rarity. Nearly always these fishes do their dirty work in packs, like wolves. When they attack a fish, unless it is small enough to be swallowed whole, one of their number usually bites off its tail so it cannot maneuver; then, when the prey weakens from loss of blood, all gather around and devour it piecemeal. A group of these fresh-water terrors do not hesitate to attack creatures more than one hundred times their individual weight, and their rapacity is equaled only by their rapidity of destruction, to which many traveler's tales testify. One day, for instance, a sixteen-year old boy, swimming in British Guiana, was heard to scream first in fear, then in agony. Before he could be reached he disappeared below the surface, and all that was recovered, a few hours later, was his skeleton. Piranha had literally eaten him alive.

As a rule, cattle walking or driven into the water are not molested by predatory packs of piranha. But should one be bleeding, either from a previous wound or a nip on the teat or leg by some piranha and other piranha are anywhere near by, it is soon dead and gone, except for its skeleton. Piranha go wild at the scent of any blood, human or animal, including that of their own kind. A wounded, weak one will be as ravenously bitten to death by its fellows as if it were a fish of another species, a duckling or a child.

So greedy are piranha that it is no trick to catch them. You do not even need to conceal your bait, and it may be any part of any animal, fish, fowl or mammal—they are not particular. You must, however, immediately haul up your catch when it is hooked or it will be seized upon and devoured by its ruthless fellows. When you have it safe in the boat you must be on guard against not getting hurt yourself, for while there is life in a piranha there is bite.

Indeed, there is nothing pleasant about this fish until it is dead. Then it makes very good eating.

Another dangerous fresh-water fish is a member of the gray shark family and lives in Lake Nicaragua, Central America. It is rightfully feared by people inhabiting the lake shore, for it reaches a length of eight feet, is very active and ferocious, and is definitely known to have attacked bathers in the lake.

Most sharks, of course, are marine fishes, and their man-eating propensities are more widely than accurately reported. For instance, it is not true, as many people think, that they have to turn over on their backs to bite. Actually sharks can bite from any angle or direction, and before they decide to attack usually cruise about their victim, swimming by and passing him several times, making a swing around him and ultimately going at him with a rush—right side up.

Nor can sharks be spotted by the appearance of fins above the water—rarely do they swim so exposed. When large fins are seen moving above the surface usually they are those of swordfish, or giant manta rays harmless to man.

Indeed, a great many cries of "Shark! shark!" on bathing beaches are false alarms. In addition to the scares created by the sight of fins belonging to other fishes, are occasioned when small boys accidentally step on sharp oyster shells or brush their legs against submerged logs and are gashed by the barnacles attached to them.

What is more, not every shark seen near a bathing beach is a man-eater, although to the public at large, and especially to newspaper reporters, the two terms seem to be synonymous.

Still another fallacy is the idea that the largest sharks are the most dangerous. Actually the two largest kinds of sharks known to live today—the whale shark and the basking shark—are harmless to man. Far from hankering after human flesh, they seem entirely to lack defensive instinct and even after they have been harpooned do not try to escape. The sharks that do attack men are the great white shark (Figure 29b), most formidable of them all, which commonly reaches a length of fifteen or twenty feet, and has been reported up to thirty-six feet; the blue pointer or mako shark (Figure

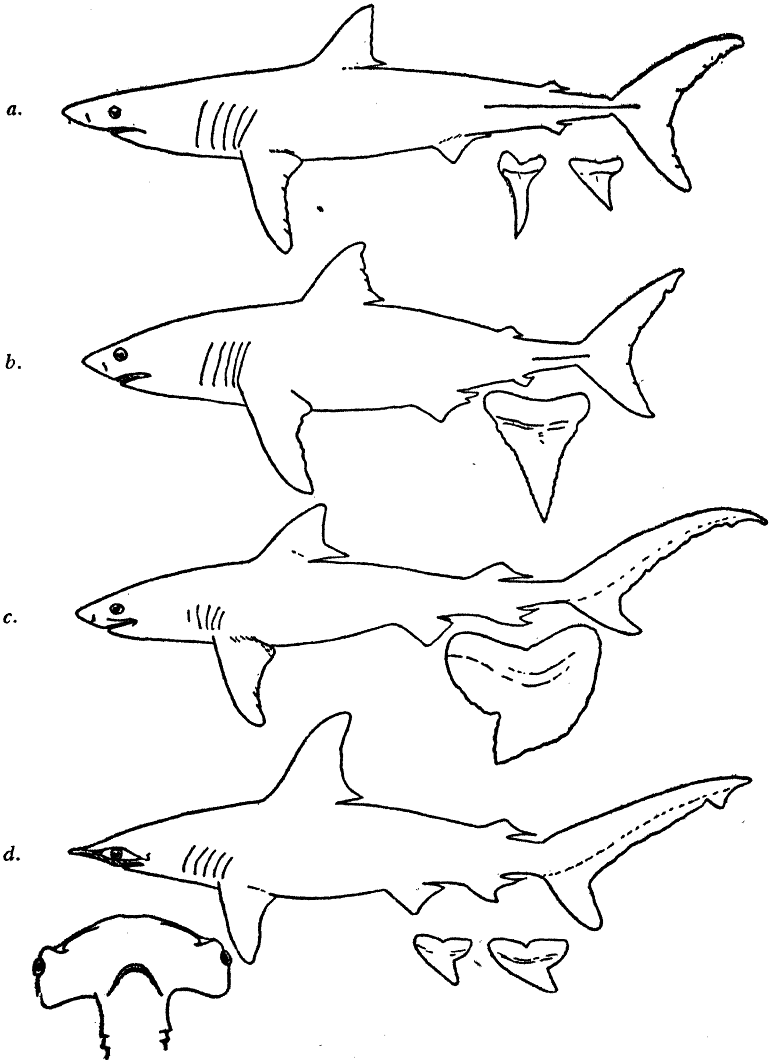

FIG. 29. Four kinds of large sharks dangerous to man: *a.* Mako shark, *Isuropsis.* *b.* Great white shark, *Carcharodon.* *c.* Tiger shark, *Galeocerdo.* *d.* Hammerhead shark, *Sphyrna.* (After Bigelow and Schroeder.)

29a), which resembles the great white shark, although it does not grow so big and is more slender; the gray nurse, or sand shark, largely a fish eater but not averse to human flesh; the tiger shark (Figure 29c), named for its markings when young; the whaler shark which makes its way up into shallow waters of Australian bays and river mouths; and the hammerhead shark (Figure 29d), whose expanded head, resembling a double-bladed axe, acts as a forward rudder and enables it to maneuver more skillfully than the rest of its tribe.

Contrary to popular belief sharks are naturally cautious and timid, although another popular concept—that they are incited by blood—is, I believe, true, on the basis of my own observation, for I have watched them grow courageous and excited at its scent. When I was on the atoll of Hull Island in the central South Pacific Ocean I attempted to capture some sharks by putting a small piece of fresh pork on a large, strong hook attached to a well-anchored chain. Three of the animals, each about three feet long, acted like hound dogs after rabbits; they scented the meat some hundred feet away. For some time they zigzagged back and forth as though trying to keep the scent, but with each forward movement they kept progressing nearer the meat. Finally, the one in the lead, when it was about six feet from the pork, made so fast a dash for it my eyes could scarcely follow. The shark ripped the meat off the hook and made rapidly off with it, and soon the others, with the stimulus of the scent gone, also swam away. At other times I have stood in lagoons with a dipnet full of fish, some bleeding, slung over my shoulder, and have seen the daring of sharks aroused by the whiff of my catch. In the beginning, as they approached, a move from me would make them scurry away. But, overpoweringly attracted, they would always come back again, each time nearer and nearer, until after a while I could no longer frighten them off. I did not carry these experiments to their ultimate conclusion; when I saw two or three sharks very bold and very close I began to feel that in their avidity they might not distinguish between me and my fish, and I discreetly left the water.

Just how often sharks have actually attacked bathers is difficult to determine. On the one hand, you have "man-eating sharks" as grist for the newspapers' mills, and on the other you have seaside resort owners who do their best to hush hush any shark-caused accidents. The late Herman Oelrichs once offered a $500 reward for an authenic case of a shark attack along the Atlantic coast north of Cape Hatteras, and although the offer stood for many years the reward was never claimed. Yet there are authentic cases of injury and death caused by sharks in this region; a boy bathing at Wood's Hole, Massachusetts, was bitten and died from shock and loss of blood; another such tragedy occurred near the New Jersey coast. In the Florida and West Indian region at least ten fully authentic attacks have been reported. On the Pacific side of North America, one in the Gulf of California and another in Panama Bay were on record before the Second World War. Dr. Gilbert P. Whitley, Australian ichthyologist, has listed almost 150 shark casualties in tropical and temperate waters of the Australian region. In short, although most species of sharks have been unjustly maligned because of some of their relatives' habits, others are truly vicious. They may bite off arms or legs of bathers, or of fishermen hauling in their nets. Worse, they may kill. In 1930 an eighteen-year old youth bathing at Melbourne, Australia, was cruelly murdered by an enormous gray nurse shark estimated to be fifteen to twenty feet long. The fish seized its screaming victim in its huge jaws, gripped him at the waist with its sharp teeth, submerged him and emerged again ten times, tossing him about like a cat torturing a mouse. Each time the animal and the youth appeared above water, they were further down the bay, leaving a bloody trail. The screams became fainter and fainter, and ultimately the shark carried its victim off and down for the last time.

Many South Sea Islanders say that large groupers or sea bass are even more to be feared than sharks, because some of them have mouths big enough to take in a man with one gulp. According to native reports these killers lurk under coral heads or back of ledges, quiet and unnoticeable until they make a dash and swallow their fish or human victims.

We know definitely that the tropical barracuda (Figure 30), has the habit of lying in wait motionless, near wharves, buoys, coral heads or wrecks, and, with sudden strong movements of its powerful tail, of rushing to attack. Anyone swimming in warm waters near rocky shores or on the ocean side of coral reefs may be exposed to these big fishes as well as to sharks, for the two occur together. There are about twenty different kinds of barracuda and all the larger ones bite. Ordinarily they live on other fishes, but occasionally, since like many predators they may attack living things stirring in the water, the object of their unwelcome attention may be a man.

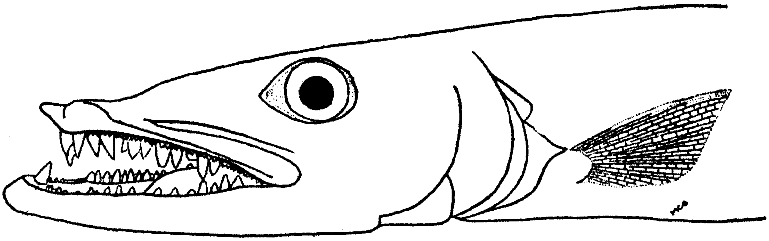

FIG. 30. Large barracuda, *Sphyraena,* have attacked swimmers in tropical seas.

Fierce and voracious as sharks, barracuda are in addition fearless—and well they may be. Specimens ten feet long have been taken off Liberia, Africa, and seven feet long in the tropical Pacific. Their monstrous mouths open wide almost back to under their eyes, about half the length of their heads, and their powerful jaws are armed with long teeth, sharp enough to pierce almost any flesh. Their rounded, long, slender bodies, blotched and barred blackish along the sides, are strongly built and easily maneuverable.

Barracuda have ripped off the calves of swimmers, have amputated legs and arms with a single bite. When death occurs as a result of one of their attacks, it is usually because an artery has been severed.

Unlike those other savage and bloodthirsty fishes, the piranha, these lead a solitary life and are seldom seen in one another's company. Like lone hunters they stalk and capture their prey. Dr. E. W. Gudger of the American Museum of Natural History, New York, observed barracuda herding schools of smaller fishes who seemed to be in such paralyzing terror that they made no attempt to break away from the spot where their giant enemy had them cornered.

But if the barracuda shows skill and ruthlessness in catching other fish, so must man in catching the barracuda. The method of taking it is to troll a spoon (a shiny swivel that turns in the water) or live bait attached to a strong steel wire, for any other material a barracuda would bite in two. Because of its size and strength, it is a popular sport fish.

Game fishes and dangerous, too, are the swordfish, marlin and sailfish, but, although they are almost as well armed with spikes that protrude from the ends of their mouths as are the bloodthirsty fishes with teeth, they never attack man without provocation (Figure 31). Indeed it is even a matter of debate among scientists as well as among fishermen whether, when they run their long spikes into boats or the men in them, the attacks are deliberate or accidental. The truth is anybody's guess. My own is that swordfish do not so much purposefully attack a definite objective as that when they are hurt they go for any object that might be the cause of their discomfort. Men have been known to hit out in blind rage at someone or something they feel may have injured them; why not fish?

In modern commercial swordfish fishing the techniques known to be used as long as 1 B.C. have been elaborated, but the two basic ones are the same—lookouts to cry "swordfish" when fins are seen above the water as the fish swims along, and a harpoon attached to a line tied to the fishing boat. Nowadays another line, some hundred fathoms long, is fastened to the detachable spearhead of the harpoon at one end and wound around a floating keg at the other. As soon as a swordfish is harpooned it dives, plunges, leaps and

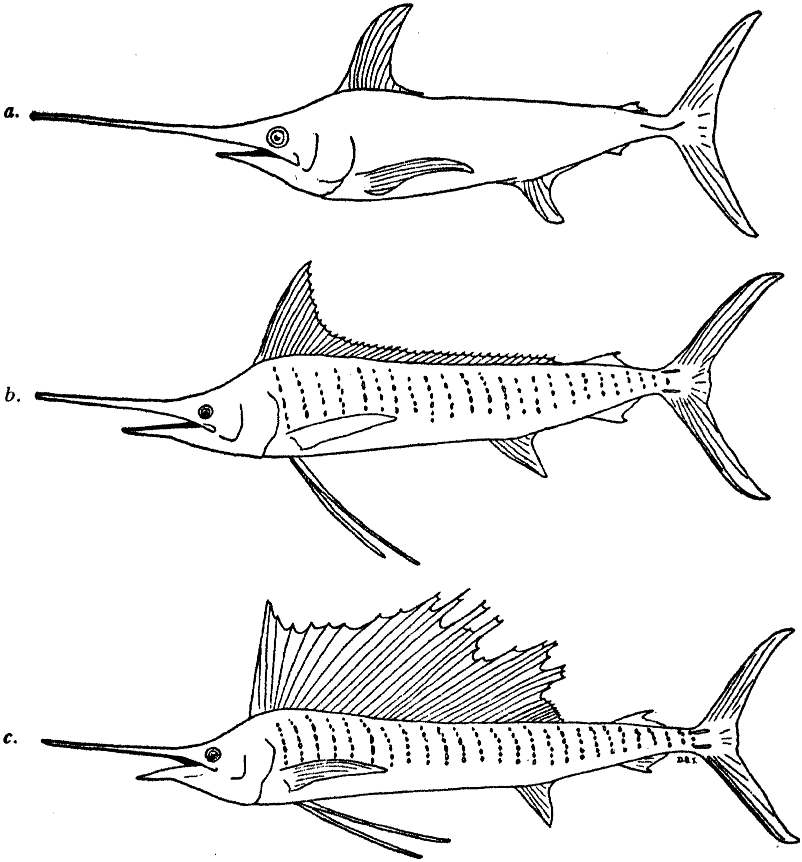

Fig. 31. The three kinds of spear fishes: *a.* Broadbill swordfish, *Xiphias*. *b.* The marlin, *Makaira*. *c.* The sailfish, *Istiophorus*.

thrashes about, unwinding the line from the keg; thus it is kept at a safe distance, although anchored. Ultimately the fish wears itself out and when activity has ceased men from the mother ship go out in a dory to retrieve prey and keg. The keg is picked up first: then the line is hauled in, dragging the fish alongside the dory, where it is given its deathblow with a lance.

Often, however, a swordfish is not as spent as it seems even to experienced commercial fishermen, and that is when it "attacks." When within four or five yards of the dory it may take off again, leaping and diving wildly, and occasionally driving its "sword" through wood or flesh. Since swordfish commonly weigh as much as 400 pounds—there is one on record weighing 600—and swim like a streak, the penetrating force of their spikes is terrific and they easily drive through at least two inches of solid planking.

There are reports of similar behavior of marlin and sailfish, and I have seen some evidence of it. When I was on Swain's Island in the South Pacific some Polynesians showed me an outrigger canoe containing a marlin's spike which had gone in one side and out the other. They described to me how the spike, with luck, had passed harmlessly between the legs of the man seated in the boat, and how it had to be chopped off because it was embedded so fast that it couldn't be extracted.

Needlefish, upon leaping into a boat after they had been hooked or netted, have pierced men's abdomens. But I have yet to be convinced that this can be attributed to nice, deliberate aiming. Rather, I believe, it was an accident that occurred in the course of the fishes' franctic efforts to escape.

Fishes That Enter Bodily Openings

Some fishes have endangered men's lives, unquestionably by accident, not because they are so large but because they are so small. Dr. Gudger, who compiled many odd facts about fishes, listed no fewer than thirty-one authentic cases of live fishes being lodged in the throats of human beings, with the outcome of strangulation or near-strangulation. Although such little trouble makers are as innocent of evil intentions as a safety pin swallowed by a baby, they can be quite as big a nuisance.

In each recorded instance of a bizarre accident of this kind the unintentional murderer had spines which prevented its dislodgement. Fortunately, goldfish have none or the goldfish-swallowing craze would have been as dangerous as it was silly.

Dr. Gudger found the oldest account of fish-in-the-throat trouble in the first edition (1678) of a book called *Wanley's Wonders.* Quaintly, it reads: "A certain Priest that was well skill'd in swimming and groping for Fish, had in a deep place, under the Banks, light of a Pearch, which to hold the better, he put into his mouth, and so to swim back to his companions; the Pearch, with her strugling, slipt so far into his Throat, that the miserable Priest was strangled by it, notwithstanding all the endeavours his associates could use to the contrary."

More recently, Dr. David Starr Jordan, ichthyologist and first president of Stanford University, received from Dr. C. Ishikawa of the Imperial University of Tokyo a preserved Oyarani, a sunfish-like little fish. There was nothing remarkable in the specimen itself but there was in the story connected with it, for it had been taken from the throat of a man. This Oyarani is now in the Stanford University Museum.

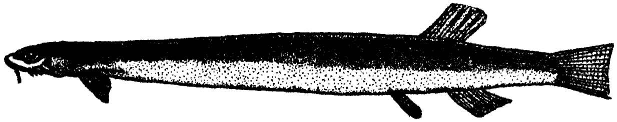

FIG. 32. The candiru, the only vertebrate parasite of man. (After Cuvier and Valenciennes.)

Still more recently, I read of a fish that swam into the mouth of a Chilean while he was drinking from a stream, and stuck there while the man choked to death.

Most of these accidents occur, however, when fishermen take live fishes in their mouths, either to kill the catch by a bite at the back of the head or to keep their hands free. Dr. Gudger lists such cases from many parts of the world, among them India, France, Italy, Burma, Ceylon, the Philippines and Hawaii. In all of them the fishes involved doubtless enjoyed their experience as little as the humans.

More purposeful is the pesky and dangerous candiru, a tiny South American catfish (Figure 32). Habitually it makes its way into the human body; it feeds upon animal flesh and blood and has the distinction of being the only vertebrate parasite. This eel-like little creature, colorless or translucent from living largely away from the sunlight, burrowing in bottom sand or mud or hidden under stones and logs, is only two or three inches long. But like the piranha, candiru do damage out of all proportion to their size.

Numerous erectile hooked spines, occurring on their heads in the region of the gill covers, give them the wherewithal for their viciousness. To how many Indians, all the way from the Orinoco River in Venezuela to the far reaches of the Amazon in Brazil, they have caused pain and suffering, nobody knows. But enough scientists, among them Dr. G. S. Myers, Curator of Fishes, Stanford University, have reported encounters with candiru to indict them. Dr. Clément Joubert, a French ichthyologist, back in 1898, came off relatively mildly. About five minutes after he was in a stream near Para, Brazil, he felt some light and rapid clawings in his abdomen, his loins and his chest. Seeing that the water near him was tinged with red, he hastened to the bank to examine himself. There he discovered that he was gruesomely decorated with groups of small bleeding cuts, five or six parallel and very close in a group. His native companions congratulated him that no bloodthirsty piranha had been about to add to his troubles.

Most anguishing and extraordinary of the experiences with candiru are those in which these fish enter the openings in the sex organs of bathers and affix themselves internally. To urinate in any of the waters they inhabit is tempting fate, for they are strongly attracted to any current. Entering the penis or vagina they may penetrate well into the urethra. There, unable to turn, in the throes of suffocation, they erect their fishhook-like spines. Their unwilling hosts, writhing in unbearable pain, are lucky if they can be rushed to a hospital in time to have their lives saved. The parasites can be dislodged only through an operation. In some cases on record the whole organ involved had to be removed.

When I was in the Río Negro of the Maracaibo Basin of

Venezuela, I collected several little fish, nearly transparent, and about an inch long, which I recognized as belonging to the group of catfishes that enter genital openings. But I dared not take the time necessary really to investigate the habits of this relative of the candiru, for it was not the only hazard of the region, the edge of the Motilone Indian country. All attempts on the part of the Venezuelan government to win the confidence of these Indians have failed, and they remain as wild as they were when the Spaniards arrived four centuries ago. Unless a party of strangers is large and transient, they shoot poisoned arrows into any trespassers on their domain. Although I had taken the precaution to be escorted by a guide and twelve husky Venezuelans armed with wicked-looking machetes, I dared snatch no more than four precious hours to explore the wonders of the aquatic life in a deep gorge of the Río Negro. I can only console myself for my lack of opportunity to study the ways of this unfamiliar catfish by thinking that even had it been possible to linger on in the region I might know no more about them than I do, for I doubt whether I would have been able to get any willing subjects for experimentation!

Fishes That Have Poisonous Flesh

Still another group of fishes harm man, but only if they are used as food. What is commonly called "ptomaine poisoning," caused by the consumption of fish—or for that matter, many other foods—contaminated or not fresh, is often confused with true fish poisoning, which results from some toxic substance intrinsic in the animal's flesh. In the tropics, where most genuinely poisonous fishes occur, any fish spoils within a very few hours: it is there, too, that frequently no doctor is available to make a reliable analysis of the cause of sickness or death. As a result, when people feel ill after eating fish, some perfectly edible fishes have been maligned as poisonous.

Altogether, however, our knowledge of the poison flesh of fishes is not only confusing because it is so often mistaken for the poison of spoilage, but also because it is appallingly scanty. Fortunately, although this gap in information should certainly be filled, it need cause no worry to residents of the temperate zones, for as far as I know no fishes with poisonous flesh appear in their markets or at their dinner tables. As for avoiding the other kind of fish food poisoning, that is simple. Never eat fish that is not fresh. Good fish flesh should be firm not slimy. You can tell a stale fish by its slimy gills, sunken eyes, flabby flesh or skin, or unpleasant odor. If, upon pressing your thumb against a fish, the fish remains deeply dented and does not come back to nearly its normal smooth surface, it may be stale.

In the tropics certain fishes should never be eaten. There are so many authentic accounts of poisoning by large barracuda of Cuba and other tropical islands that there must be some truth in the general belief they are toxic and they should be put on the dangerous list. The malady that results from their consumption shows itself in pains in the joints and extremities, nausea and vomiting and general trembling, and is called ciguatera by Cubans. Death sometimes follows ciguatera. Apparently, however, barracudas less than three feet in length are not poisonous.

In the coral islands of the Pacific the red snapper and certain jacks are reported to be poisonous at certain times of the year, or from certain areas about an island. Such temporary or localized toxicity, it is thought, may result from the fishes' eating some poison-creating marine animals or plants. Some credence can be given to this theory because we know that another sporadically poisonous marine animal, a blackish mussel of the west coast of North America, causes death when it is eaten at the time it is feeding upon some small organism that affects its flesh. Also, it is definitely known that the eggs of certain fishes are poisonous, although the fishes themselves are not. (Dr. Hubbs became very sick after eating some eggs of a United States Pacific Coast marine sculpin.) Possibly the flesh of the females of certain fishes is poisonous only during the breeding season while the eggs are developing.

Some trigger, file and trunk fishes have been reported as being poisonous, but many are not. During the war, a Scandinavian sailor who had been torpedoed came into my office to identify a kind of fish on which he had lived for weeks while he was adrift on a raft; a school of them, he said, had constantly stayed under the raft, and he had caught them with a line made of fibers from his clothing and a bent safety pin as a hook. When the safety-pin hook was lost, he pulled a nail out of the raft with his teeth, bent it, and continued to catch his food. He described the fish which had saved his life as having, among other features, one rough spine standing out from the back of its head. I took him with me into the Museum's storage vault and pulled down jar after jar of fishes I recognized as belonging in the classification of the fish he had lived with and on for so long. Suddenly he cried, "That's the fish!" The specimen was the file fish, which has too loosely been called poisonous.

Similar accusations have been made against the trunk fish, which occurs in tropical shore regions. Yet the fact remains that many, many times this bony-plated animal has been put into the oven; that many, many people have enjoyed the flesh baked within its hard covering, without any ill effects, and that they have lived hale and hearty to tell the tale.

Among the puffers, also generally lumped as poisonous, some are not but most are. These fishes have the ability, when endangered, to blow themselves up like so many tires. Certain of them are covered with rough skin; others, the porcupine fishes, also have long sharp spines. When a porcupine fish is deflated its spines lie flat; when it puffs itself up it bristles like a filled pincushion. Dead or alive, it is a fish to beware.

Another fish it is the better part of valor to omit from the dinner menu is *Ruvettus pretiosus* (Figure 33), commonly known as the "oil fish" or "purgative fish." The baneful qualities of its white, flaky, rather tasty flesh have been known for over a century but every now and then, like toadstools, despite the common knowledge about them, it causes trouble in a big way. The most recent instance of oil fish poisoning that came to my attention was during the war. One day a Navy doctor came to my office with a report of fish-caused casualties in a camp on Saipan. No fewer than 51 individuals who had partaken of a 55-pound fried fish had fallen ill; most of them seriously. Their immediate symptoms were tingling and numbness of the tongue, hands and feet, pains in the chest, abdomen, and general weakness. All perspired excessively and had difficulty in walking, talking, swallowing and breathing. Three hours later, muscular spasms occurred, with more severe pains in abdomen, chest and legs, and half the men passed into a state of shock. Many patients suffered spastic paralysis of arms and legs; some had blurred vision and one man went totally blind for two hours. Contact with cold water caused such a painful sensation of burning that for three days none of the sick could take cold showers. For five days, they couldn't drink cold water. General weakness lasted for two weeks. Happily, thanks to blood plasma transfusions, all the men recovered.

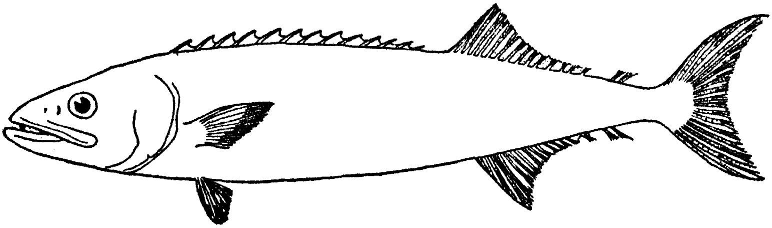

FIG. 33. The oil or purgative fish, *Ruvettus,* of the open seas, has poisonous flesh. It should not be eaten.

Naturally, the Navy was interested in having the guilty fish identified in order that another such catastrophe might be avoided. The doctor had with him a rough sketch of a fish, shaped something like a barracuda, and an inadequate description. The guesses of the people on the spot were that the offender was a barracuda. The statement was made by a

Japanese doctor that the fish had four dog teeth hanging down at the front of its upper jaw. These teeth were my clue: I knew this had been no barracuda, and suspected the oil fish at once.

Polynesians use small quantities of the oil of *Ruvettus* as a laxative, and they say that its flesh is safe to eat if it is thoroughly boiled and the liquid poured off. Although I have had many occasions to respect native knowledge of fishes, I would not however, knowingly eat an oil fish.

Not only do fishes differ in their edibility, but also in what and how they eat. Diverse are the ways in which their food is caught and consumed.

5

FEEDING HABITS

In the last analysis the feeding of fishes goes all the way back to light and inorganic matter, which cause plants to grow. Next link in the complicated chain ending with colossal fishes consists of aquatic plants, algae and diatoms. These, in turn are the food for microscopic animal organisms, insect larvae, crustaceans, worms and other low forms of animal life, which are eaten by fishes. Larger fishes eat smaller fishes, and so all the way up to the most tremendous predators.

Within this sequence, some fishes are exceptions. There are sizeable fishes that feed directly on the tiny, free-floating plants and animals.

Also, in the over-all picture of eating to live, certain fishes have characteristic and peculiar ways of obtaining their food.

The hunters and fishermen among men have their counterparts in the waters and it is no "nature faking" to say that some fishes obtain their food by shooting it, while others use rod and bait.

Fishes That Shoot Their Food

The marksmen are the six kinds of archer fishes; their weapons are their mouths, their ammunition drops of water (Figure 34). Like the shot from an airgun, these drops are so forcibly expelled and neatly aimed that they knock down insects, sometimes even in flight, into the water, where they are quickly devoured by their assailants.

So apparently fantastic is this peculiar habit of the archer fishes that the first reports of it were not believed. Back in

1764 a Mr. Hommel, Governor of a hospital in Batavia, described in a letter to Dr. John Albert Schlosser, zoologist in Amsterdam, what he knew about a fish he had named "the jaculator or shooting fish." Local fishermen had told him, he wrote, that it frequents river shores in search of food; when it spies a fly sitting on one of the plants that grow in shallow water, it swims on to a distance of four to six feet from the insect and then, with surprising dexterity, ejects from its mouth drops of water that never fail to strike the fly down into the stream. Hommel, however, was not satisfied with hearsay and decided to study for himself the habits of this curious creature. He had a large cask filled with water and in it placed some archer fish. When they seemed at home

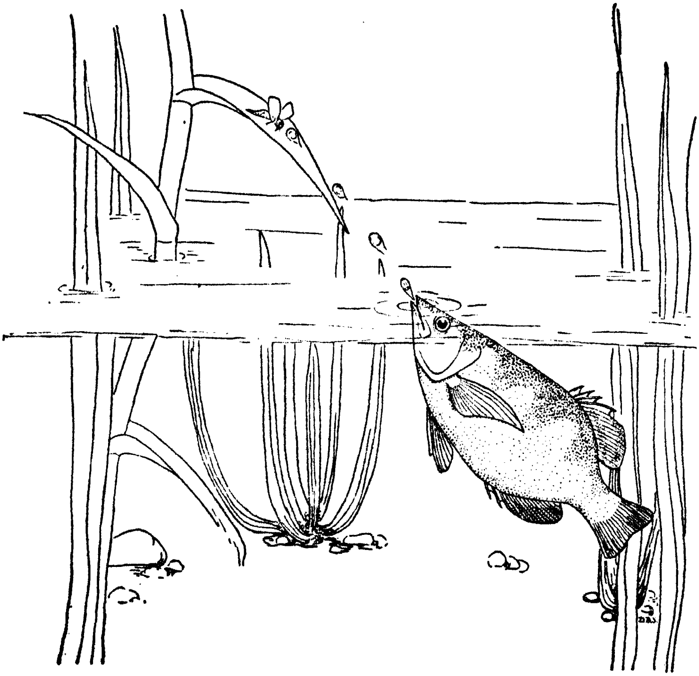

FIG. 34. The archer fish, *Toxotes,* of the southeastern Asiatic region, shoots insects off objects by means of droplets of water. This is a highly specialized method of feeding.

in their new surroundings he provided them with a target—a fly pinned to the end of a stick leaned against the barrel so that the fly rested above the top. Daily and delightedly he observed his fascinating captives shoot at the fly and seldom miss.

Unfortunately when Hommel had selected what he believed was a specimen of his "jaculator" he made a mistake and sent Dr. Schlosser a species of fish that could not possibly do the things he described. As a result his observations were discredited. Although a year later a correct specimen did reach Europe, the Russian zoologist Pallas added confusion to confusion. As if he were filing a letter in the wrong folder, he mistakenly classified the archer fish with the drumfish family, to which it is not even remotely related, and Hommel's account of its habits was in limbo for over a century.

Then, in 1902, the Russian ichthyologist Zolotnisky proved that Hommel had been no Baron Münchausen but a sound reporter. By means of observations and experiments on a number of captive archer fish obtained in Singapore, Zolotnisky not only corroborated the eighteenth-century amateur's findings, but also discovered many new facts about these fishes' behavior.

Later, Dr. Smith added further details to our knowledge of the shooting fishes. Until he investigated them nobody knew how they were able to propel drops of water with so much force and accuracy. By a study of the mouth of *Toxotes,* one of the archer fishes, Dr. Smith found that it has a special mechanism for this purpose (Figure 35). Lengthwise along the roof runs a groove, with a funnel-like opening at the rear. When the fish presses its tongue against the roof of its mouth, the tongue and groove form a tube, the gill covers are compressed, and the paper-thin, flexible tip of the tongue serves as a valve that keeps the water under pressure. As the tongue tip is lowered, i.e. the valve is released, out shoots a drop of water from the front or mouth end of the tube. Through further manipulation of the tongue a series of drops may pop forth in rapid succession.

Accuracy of aim is attained by the archer fish's exceptionally keen aerial vision. When it approaches within a short distance of an insect it wants as food it stops—at the surface if the water is muddy and slightly below if it is clear—and points its head and eyes towards its prey. At such moments writes Dr. Smith, "Its eyes sparkle with seeming intelligence, and their mobility is noteworthy. They can be directed laterally, upward and backward. . . ." This sharpshooter's ability to see in air, so good that it is able to select its food, is probably more important to it than its ability to see in water, for it lives most of the year in muddy waters and eats aquatic creatures, such as shrimps and worms, but only as second choice to the insects that hover over water or rest on overhanging plants.

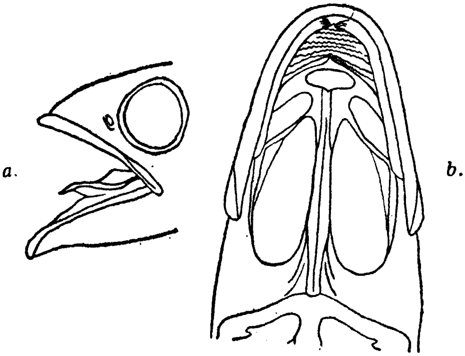

FIG. 35. The mouth and tongue of *Toxotes,* showing the mechanism for ejecting droplets of water. *a.* Tongue. *b.* Roof of mouth. (After Smith.)

Early in life the archer fish starts to learn its hunting techniques. Babies send tiny drops only a few inches, but by the time they are half grown they can shoot down their own food. Mature archer fishes have skill unsurpassed by the champion slingshooter of any neighborhood gang of boys. Nicely, they achieve just the proper amount of force needed to shoot down insects at various distances up to six feet away. With astoundingly few misses they discharge watery "ack ack" batteries at insects in flight.

Dr. Smith, when he was expert fishery advisor to the King of Siam, used to get fun and chuckles out of the performances of some archer fish that lived in a pond adjoining his home in Bangkok. Friends, sitting and smoking in comfortable chairs on the verandah, would be startled, annoyed or amused, according to their temperaments, when suddenly drops of water would douse the lighted ends of their cigarettes, exactly as if someone were doing some well-directed spitting.

Spitting is not as elegant a word as ejaculating. But whatever the archer fish's manner of downing its prey be called, there is no question about its being effective.

Fishes That Fish

Equally specialized and well equipped for food-getting is *Lophius piscatorius,* popularly known as the angler, goose or frog fish (Figure 36), which lives on bottoms of the North Atlantic and is common along the coast of southern Canada and the United States. This finny Izaak Walton has rod, bait and trap as part of its anatomy.

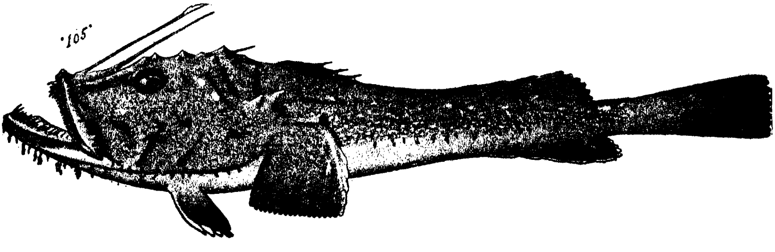

FIG. 36. The angler or goosefish, *Lophius piscatorius.* This fish has a rod with bait for fishing.

The rod is a modification over the ages of dorsal fin spines, and on a three-foot angler fish may be nearly a foot long. From its tip dangles permanently attached bait; this consists of fleshy, worm-like tentacles that can be expanded and contracted. The trap is an over-sized mouth armed with long, sharp teeth. It has the ability to create an ingoing current.

Ordinarily the rod, which can be moved forward and backward, lies down against the fish's back. When the animal gets the urge to eat it alerts itself about two feet away from its intended catch—usually a little fish—pushing up the front of its body and tensing its pelvic fins. Then it moves its rod up and forward so that the bait swings alluringly just above its upper jaw. The smaller fish nibbles on the harmless looking tentacle, dangerously near the angler fish's huge mouth. That cavern, as much as ten inches wide on a three-foot angler fish, opens and into it is sucked the little fish.

If the fishing tackle of an angler fish has resemblances to that of human fishermen, so has its temperament. It is an easy-going creature that likes to be alone. Living in solitude in nooks among seaweeds or stones, it makes no frantic scurries for its food but lies in ambush simply waiting for a fish to come along and be caught. On the sea bottom it is inconspicuous to its prey. Its head, irregular in outline, with ridges on the upper surface, resembles a rugged rock and is so large in proportion to the rest of its body, which tapers sharply off into a small tail, that the fish seems to be all head. The whole fish is covered with series of little fleshy projections which wave back and forth with the motion of water and are almost indistinguishable from seaweed. Those anglers that inhabit the deep sea are jet black.

Not only fishes are victims of one species of these well-camouflaged and well-outfitted anglers. Occasionally the frog fish swims to the surface and eats ducks, gulls, geese and other sea birds that dive to feed under water. Dr. Gudger reports finding a bird lodged in the throat of one frog fish whose appetite was bigger than its swallowing apparatus.

Dr. William Beebe, director of the New York Zoological Society, observed the habits of the dwarf angler fishes in an aquarium containing other small fishes. He saw sea horses devoured. He watched the fish approach bait, wriggling like a worm (Figure 37). When they were still two inches away from the angler's protruding lower jaw, it opened its mouth with no apparent effort and they disappeared before Dr.

Beebe's eye could follow. "We imagined a gleam of satisfaction in the fishy eye," he wrote. Similar gleams are not unknown in the eyes of successful human fishermen!

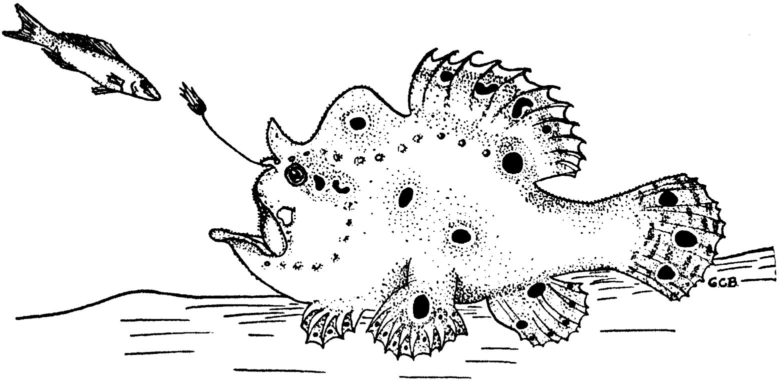

FIG. 37. The dwarf angler fish, *Antennarius,* by means of the fishing rod and its bait at the tip, attracts small fishes to nibble on the wormlike tentacles. Suddenly the angler's mouth opens and the unsuspecting little fish disappears. Some of the deep-sea angler fishes have a luminous bulb at the tip of the fishing rod.

As if it did not have sufficient distinction in its way of catching food, the angler fish is also distinctive in the way it lays its eggs. It is one of the three kinds of fishes—the other two are its dwarf relatives, *Antennarius,* and the yellow perch—to deposit them in jelly-like ribbons. These elongated masses are found sometimes floating on the surface, sometimes stuck to wharves. Two were found by Dr. William Proctor, Director, Mount Desert Biological Station, under a wharf in Frenchman's Bay, Maine. They were pinkish lavender in color, about a foot wide and twenty-five to thirty feet long—almost eight to ten times the length of the fish that laid them. Truly, *Lophius piscatorius* is one creature that merits the over-used appellation "queer fish."

Fishes That Feed by Sucking Blood

Less strikingly designed for feeding, yet still possessed of distinctive apparatus, is the lamprey, frequently miscalled the lamprey eel. Unlike other fishes it has no jaws that open and shut. Its round, disk-like mouth, bordered by fringed lips, is especially adapted for attachment to other fishes whose blood the lamprey sucks for nourishment.

The general run of fishes would not be able to breathe under such circumstances, for they must open their mouths to take in the water from which they derive oxygen. Lampreys, however, have along the sides of their heads several little round openings connected with their gill chambers. While their mouths are fastened tight to their prey, these fishes are able to breathe water in and out the openings.

I had my first experience with a lamprey when I was fifteen years old. I had caught a rather large catfish in the Kalamazoo River, Michigan, and saw, attached to it, an elongate, dusky, mottled, six-inch eel-like creature the like of which I had never before seen (Figure 38). When it fell off the catfish into the grass of the river bank it flopped about trying to get back into the water. My brother Arch came to my assistance at my call, for even at that age I could not bear to let a strange new fish get away from me. Our attempts to pick up the slippery little animal failed until it attached itself to my hand. Distinctly I could feel suction, and I jerked away in surprise. Arch snatched the creature and put it in a basket, and then I noticed that the catfish still on my hook had a fresh, round sore on its back, just behind the

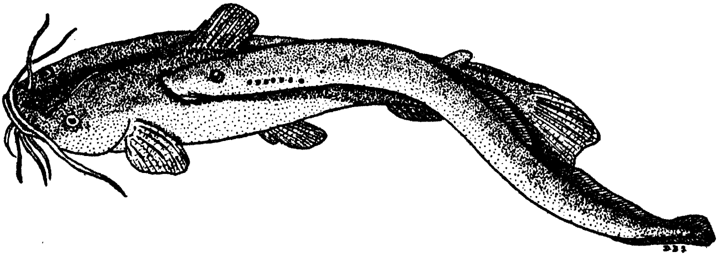

FIG. 38. The parasitic lampreys attach themselves to fishes, rasp off the skin with their toothed mouth, then suck blood of fishes both in the sea and in fresh water. Here a lamprey is attached to a catfish.

head. Around the wound was a ring of tooth marks. Upon examination of the lamprey after it had died, I could see rows of sharp-pointed teeth radiating from its throat or tongue.

Afterwards I asked my fishermen acquaintances what this "blood sucker" was and they called it an eel, but several years later at college I learned that lampreys do not belong to the true eel families. For many years I thought and wondered about the unusual fish I had inadvertently caught, but not until I had begun teaching ichthyology at the University of Washington did I really have the opportunity to investigate the lamprey.

Lampreys occur in temperate and subarctic latitudes nearly all over the world except, for some reason I do not know, in southern Africa. There are two kinds of them: the parasitic —like the one I met during my boyhood—which after maturity live by sucking blood, usually that of other fishes to whom they attach themselves, and the non-parasitic. The parasitic ones go down to the sea like the salmon, returning to fresh water to spawn. The sea-run lampreys of the Atlantic and Pacific coasts of North America, tubular in shape and devoid of paired fins, reach lengths of three feet and weights of about two pounds.

Lampreys have their practical uses for man; to a limited extent they are used as food, and they make good bait for bass. But the parasitic members of the family can also be a great nuisance. In the Greak Lakes, where they have become abundant during the past few decades, they frequently and annoyingly attach themselves to swimmers. Fishermen, both commercial and sport, also have grievances against them; many fish in their catches are defaced by bad scars and sores caused by lampreys. Recently, bills for the control of lampreys in the region have been introduced into Congress.

The hagfishes, a scourge in certain muddy bays and along sea coasts, are relatives of the lampreys. All these parasitic, voracious fishes spend their whole lives in the sea, some kinds in deep water. They attach themselves to other fishes and burrow into their flesh, rapidly consuming blood and flesh as they progress. Hagfish have been reported to consume several times their own weight in a few hours.

Although the feeding habits of such fishes are a headache to man, because more edible and commercially valuable fishes are decimated, the feeding habits of others are helpful and have been turned to good use.

Fishes That Feed on Insect Pests

In regions where mosquitoes carry the diseases of malaria, yellow fever, dengue fever and filiariasis, small fishes that enjoy and thrive upon insect eggs and larvae are life savers, and for nearly one hundred years have been cultivated and used for mosquito control. Even with the recent advances in the use of DDT the use of such fishes will remain important: for one thing, DDT is a more expensive means of control and for another it is likely to kill wanted fishes as well as unwanted mosquitoes.

Like all insects, mosquitoes pass through various developmental stages; eggs, larva, pupa and adult insect. It is in the first three of these that they can be most effectively controlled. The eggs are usually laid at night or in the morning on the surface of sluggish water; some kinds of mosquitoes lay their eggs singly, others in raft-like groups. For two weeks, from the egg through the pupa stages, these potential murderers remain in the water, a menace to man but the staff of life to certain small fishes.

For mosquito control these natural enemies of immature insects are introduced into waters where they are not already abundant. Not any fish, however, may be a chosen member of an anti-mosquito corps; there are definite qualifications. A fish must be carnivorous but uninterested in the young of other fishes. It must feed near the surface. It must occur in warm climates. It must breed rapidly in tiny bodies of water —the whole life cycle of the yellow-fever bearing mosquito may occur in something as small as a tin can. It must be at home among aquatic plants, for mosquito eggs are usually laid in the midst of protective vegetation.

Most experimenters have found native fish best for mosquito control, but where none occur, imported fishes can be acclimated. Nearly all the top minnows make excellent aides to public health officers and sanitary engineers, with the *Gambusia* as champion. Throughout the summer it breeds, giving birth to live young at five or six weeks' intervals; in the southern United States, a *Gambusia* produces half a dozen generations of mosquito fighters a season. The larger the female the more numerous her offspring; thirty to sixty in a brood is the usual number, but there may be as many as one hundred. Although young *Gambusia* are only half an inch long at birth, they are immediately active, and before they are a day old the babies are already doing their bit as guzzlers of mosquito larvae. At the still tender age of four or five months young *Gambusia* become parents. Thus the children of *Gambusia* born early in a season, do the same good work during that same season in the same pond as their parents.

The more plants there are in a body of water, the more fish are needed to keep it mosquito free. But since the enemies of *Gambusia* are birds and certain other fishes, protective vegetation of the kind that appeals to egg-laying mosquitoes is actually an asset to it.

Dr. S. F. Hildebrand, Senior Ichthyologist, U. S. Fish and Wildlife Service, found in experimenting with this fish that one adult female ate one hundred and sixty-five large mosquito larvae in less than twelve hours. From the Philippines, where *Gambusia* was introduced, Alvin Seale, former director of the Steinhardt Aquarium, San Francisco, reported that one year between December 9 and February 25 one adult pair put an end to 5041 mosquitoes, each of which might have infected one or more humans. In all its habits, in short, *Gambusia* seems made to order as an agent of mosquito control.

None of the top minnows occurs in very high altitudes, so in the mountain brooks of South America little catfishes and the voladora are valuable in mosquito control. In India and Siam, relatives of the top minnows are used. Nearer home in backyard garden pools a few goldfish or brook minnows may supply more than picturesqueness by stopping the flight of mosquitoes towards the house before it has a chance to begin.

Fishes That Feed Diversely

Quite a contrast to the dainty diet of insect eggs and larvae eaters is the food consumed by some voracious sharks, which seem to have no more discriminating appetites than goats. An intact 100-pound bag of flour was found in a dissected thirteen-foot-eleven-inch long tiger shark at Bikini. Dr. Gudger reports finding in the stomachs of other tiger sharks, a horse's skull, the dehorned head of a cow, the leg bones of a horse, and a hoof with iron shoe attached, respectively. The animal matter was partially decomposed and had apparently come from dead animals which had been thrown overboard. In the stomach of a twelve-and-a-half-foot long hammerhead shark, Dr. Gudger discovered the skeleton of a large stingray. Fifty-four stingray stings were lodged in the mouth of another hammerhead shark. I have found whole eels and squids in the stomachs of black-tipped sharks.

Occasionally fish, like human beings, eat indiscreetly. A ration of sharp-tailed or snake eel, for example, ought to be avoided by any fish that wants to live sensibly. This eel has a sharp-pointed tail normally used for burrowing in gravel and sand but when swallowed it has been known to burrow right through its devourer's digestive tract. Dr. Breder found a two-foot-long snake eel who had done this and was mummified in the body cavity of a four-foot grouper. Small fishes with erectile spines, especially those equipped with locking mechanisms, also make unhappy eating. Normally the two spines of the trigger fish lie down, but when it is excited (and certainly it is excited when it feels itself being swallowed by another fish!) the front spine, so strong and heavy that the whole fish can be lifted by it, stands up, while the smaller one behind makes it fast. No amount of pressure, twisting or turning will unlock the erected spine so that it falls again; the trick is to press down a bit on the smaller spine. With catfishes you have to know the unlocking combination, too; it involves rotating and pressing down on the locked spine at just the correct angles. Of course, a fish with a locking mechanism is able to do its own unlocking, but a fish that tries to eat it is helpless, and sometimes both fishes die, just as humans have died when a spiny fish is caught in their throats.

Those gentle creatures, whale sharks, the giants of the shark family, have small throats in which any sizeable fish might get stuck, but their feeding habits are such that they do not get into trouble through gluttony. They are the enemy of no creature larger than a small sardine and, like the basking sharks, feed largely upon plankton which is strained out of the sea water by fine gill rakers at the backs and sides of their mouth cavities and throats. Sluggish in their habits, whale sharks could not swim speedily enough to catch fast-moving fishes if they would. When they want to eat they swim slowly at the surface or just below, with their mouths open, for a short while; then they dive and turn, on the way back taking in their little morsels. In compensation for their slow motion they have four-inch thick skin, strong and tough as a truck tire.

The teeth of these big animals are so tiny that a dime will cover three or four of them, and are not used in feeding. On the other hand, to many kinds of fishes, their particular type of teeth is of the utmost importance.

Parrot fishes, so called because their teeth are shaped like beaks, are adapted to scraping vegetable matter off rocks. I have seen herds of them, their dazzling blue-green backs half exposed above the water, grazing on algae on coral reefs; later examination of the coral, scraped clean, showed it to be covered with teeth marks, scratches and cuts. Once I found a group of these parrot fishes whose cheeks and lips were covered with petroleum, for all the world like youngsters who had explored a jam jar: they had grazed near a wrecked tanker.

Whether other fishes' teeth be scalloped for scraping soft algae (as in butterfly and surgeon fish), or slender and pointed for seizing prey (as in many sharks), or scissor-like for chopping out hunks of flesh (as in piranhas and some sharks), or rasping (as in lampreys and hagfishes), or crushing (as in rays, skates, and some minnows), or hinged so that when erected they prevent small fish from escaping (as in groupers), always they are right for what the fish eats. Or it might be said that what the fish eats is right for the kind of teeth it has. It does not matter: the fact of adaptation remains.

And teeth are only one of the anatomical structures that vary with feeding habits. Because the digestion of vegetable matter by fishes is more involved than the digestion of animal matter, vegetarians such as the stone-roller minnows and certain suckers have long intestines, often coiled many times around their air bladder; while carnivorous predatory fishes, some of whom swallow their prey whole, others of whom chew it up, have shorter intestines with only one or two loops.

Mouths differ widely in size and shape. Such fishes as gars and needlefishes have long jaws enabling them to seize prey. Others, for example the mormyrid eels of Africa, have tubular mouths which they insert in spaces between stones. Trumpet and pipefishes also have tubular mouths, whose minute jaws are suited for seizing small crustaceans.

Weirdly but purposefully placed are the mouths of the flat fishes, flounders and soles; like these animal's eyes, they are not set in the middle of their faces like other creatures but over at one side. When flat fishes characteristically lie partially buried on bottom sand, they can still eat comfortably, like so many Romans dining from their couches.

The sea devil, or giant ray, has a unique feeding device. Its pectoral fins, prolonged forward, form a pair of fleshy appendages or horns—hence its name. In *Mobula,* one kind of sea devil, these horns normally are curled up tight; when this fish, which feeds in a group, spies a school of little fish, it uncurls its horns to form a funnel leading into its mouth.

Almost all those fishes which feed in the dark detect their food by means of barbels or filaments, sensitive to touch. These feelers are attached to their chins and snouts and can be extended forward and waved about; the moment they come in contact with food the fish is aware of its presence as surely as if it saw it. Usually the fishes with effective barbels have small insignificant eyes; the catfishes have the most highly developed barbels of all.

But a mere listing of special modifications for feeding would almost fill a book. Suffice it to say that in some special way all fishes are well fitted for the life they live and the food that is available to them. Otherwise they would not have survived in the evolutionary process, and we would not have the thrill of contemplating their infinite variety, including those which fend for food for others besides themselves.

6

ASSOCIATION WITH OTHER ANIMALS

GENERALLY, one does not think of one kind of organism as living with another. Yet throughout the world of plants and animals certain organisms take up their abode with others in quite different categories. Sometimes one member of the partnership is more benefited than the other; sometimes the arrangement is mutually helpful; sometimes one gains and one loses by it.

At its most one-sided, such association is called parasitism; in this, an organism draws nourishment from its host and gives nothing but irritation or debility in return. At its most mutual, it is called symbiosis. When fleas live with a dog, there is parasitism; the insects benefit, but the dog definitely does not. When dogs live with man, there is often a kind of symbiosis. In exchange for the food and shelter provided by man, the dog may give protection or service.

A clear-cut instance of symbiosis is the association between two kinds of insects, ants and aphids. The ants take care of the aphids, and the aphids provide nourishing and delectable syrup for their nurses. Termites symbiotically shelter certain microorganisms in their digestive tracts; these reciprocate the hospitality by facilitating the digestion of the wood the insects eat. Similarly there are microscopic plants in the intestinal tract of man. As if they were grateful for the security—for they cannot live elsewhere—they help him to digest his food.

Another kind of plant, green or colored algae, lives in the fresh-water hydra and sea anemone. The algae do more than contribute brilliant coloration to their hosts; they use up the carbon dioxide and other waste products of the animals' bodies and in return supply oxygen. In Eniwetok Atoll, I saw an amusing example of symbiosis; globular sea urchins were using wafers of algae, about the size of fifty cent pieces, as both camouflage and sunshades. The animals, which were exposed where the surf broke on an open reef, manipulated their tubular feet to pick up the algae and place them on top of themselves. The algae, getting more light than they had had before, were thriving.

Interesting though all these symbiotic combinations are, of course I think the ones involving fishes are the most fascinating and curious of them all.

Fishes That Live Symbiotically

For instance, there is the way damsel fishes join forces with other animals. Generally these little creatures, two to four inches, and pretty as their name with their brilliant multicoloring of yellow, black and silver, reside among coral branches. At the slightest sense of danger they will dart into their dwelling place. When they are there they feel so safe that I have broken off the top of a coral with not one member of a whole school of damsel fish in its lower part as much as fluttering a fin in fear. Once I brought home a coral branch from the South Pacific for my children. Not until the long journey of thousands of miles was over, and months after the coral had been standing in our living room, did I notice, sticking in some of its crevices, three little dead and dried-out damsel fish which had clung to their home to their last gasp.

Sometimes a pair of damsel fish will live together in an interstice, zealously guarding it from intruders and driving them away whenever possible. Dr. Herre observed the habits of several species of *Amphiprion,* one of the damsel fishes. This member of the family dwells in the giant sea anemones, sometimes two feet in diameter, which are widely distributed throughout the western tropical Pacific Ocean;

certain species of *Amphiprion* are found only in one kind of sea anemone, others occur in several (Figure 39).

These sea anemones quickly kill other fishes and animals such as shrimp which are unfortunate enough to touch their stinging cells, but for some as yet unexplained reason their poisoned tentacles carefully curl away from any *Amphiprion* darting among them. Sometimes a male and a female keep house together. Sometimes each has a home of its own and they visit back and forth. The male stays with the young until they are big enough to take care of themselves, when they are driven forth to find anemone homes for themselves.

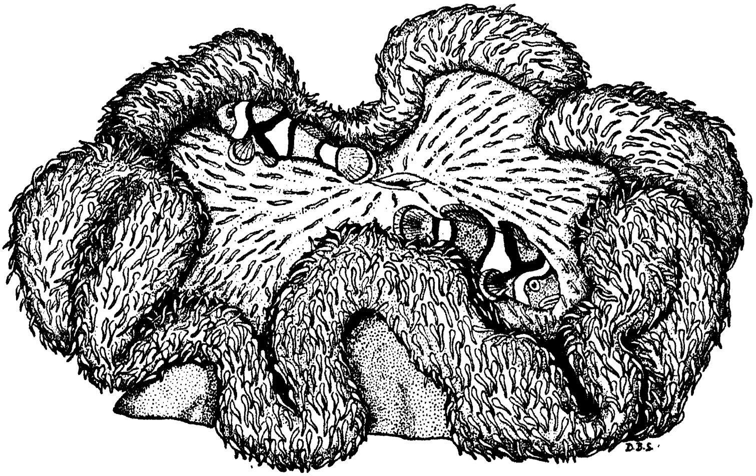

FIG. 39. The symbiotic association of the damsel fish, *Amphiprion,* with the sea anemone, *Discosoma,* is mutually beneficial. *Amphiprion* does not occur except in association with sea anemone, but *Discosoma* may not have an *Amphiprion* living among its tentacles.

In exchange for their safe and cozy residences the damsel fishes act as the providers for their hosts, handicapped as food gatherers because they are fixed in one place. Timid swimmers, the *Amphiprion* do not venture far from home. When they spot food they make a dash for it, seize a mouthful, hurry back to the sheltering anemone and drop the find among its tentacles, which seize it. Promptly the fish rush back for more food and again place it in storage, until the available supply is exhausted. Other fish may have been feeding at the same source, but usually the *Amphiprion* get the lion's share of the food because they do not have to pause to consume their rations on the spot. Instead they return home and dine at leisure, generously sharing their haul with the sea anemone that has provided a well-guarded pantry.

A somewhat similar symbiotic partnership exists between the small fish *Nomeus* and the stinging animal *Physalia,* the Portuguese man-of-war, a particular kind of so-called jelly fish which in common with all the jelly fish is not a fish at all but a Coelenterate like the sea anemone. *Physalia,* occurring in the deep blue waters of all warm seas, has a bluish float and long, translucent streamer-like tentacles that droop into the water. All along the streamers are tiny pear-shaped nettle or stinging cells containing a coiled, spring-like thread. At a touch upon the tentacle or the pear-shaped unit, a trigger mechanism automatically releases the thread with its spear-like point, which, carrying a substance similar to the formic acid found in bees, shoots out against the contacting creature or object. It immediately punctures human skin; the wounded victim suffers spasms, shock and several days' prostration; it is as if he were stung by a swarm of bees. Dr. Smith told me that when he was in the Philippines he saw a sailor, who wanted to take a swim, dive off his ship right into a group of the Portuguese man-of-war. The sailor nearly became deranged from the pain.

For any kind of little fish save one, *Nomeus,* the consequences of proximity to a Portuguese man-of-war are even more dire. It is instantly stung and shortly paralyzed. The *Physalia*'s tentacles pull the hapless fish up to its little sucking mouths which spread funnel-like over it to start the process of ingestion. All the parts digestible for it are consumed and the rest ejected.

The Portuguese man-of-war is all the more a death trap because out in the open sea unwary little fishes trying to

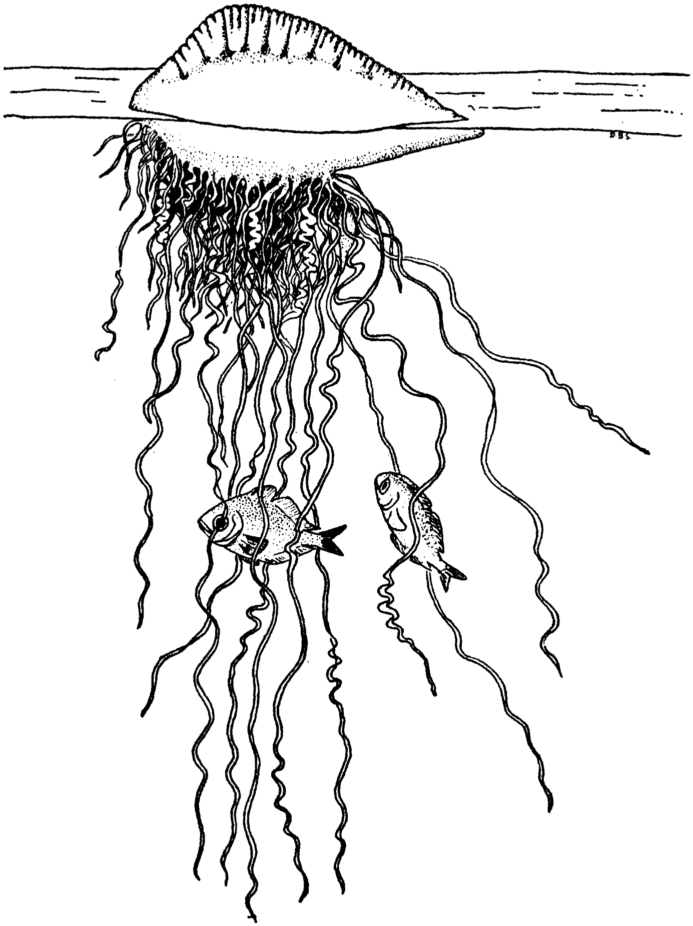

FIG. 40. The sheppard fish, *Nomeus,* lives among the tentacles of the Portuguese man-of-war, *Physalia.* It is immune to the stinging cells of *Physalia.* Both occur in the tropical open ocean.

escape from predator fishes after them from below or birds from above tend to head straight for it. All collectors in the open sea know the importance of scooping up seaweed or any floating object for very likely there will be safety-seeking fish in the haul. Where there is no shelter afforded by shore line or reef, where there are no logs or stones under which to hide and usually not so much as seaweed, any floating refuge, even for a moment, may represent the difference between life and death. To a frightened fish the *Physalia* seems just such a refuge; and so it goes to its doom.

Yet commonly found swimming around, among and under the tentacles of this terror to all other sea life, are numbers of the purplish to bluish fish, *Nomeus,* safe and protected as pet guppies in an aquarium. *Physalia* provides them with food as well as shelter for, like dogs enjoying scraps from the table, they feed upon the parts of food discarded by the larger creature. It is not known why this single fish is spared, and supplied housing to boot, by an animal lethal to others, but one need not come to a sentimental conclusion that it is because of any coelenterate equivalent of humanitarianism. By serving as a lure *Nomeus* probably well repay the Portuguese man-of-war for its generosity. Other fishes, seeing them swimming about in a danger zone, do not see it for what it is; they venture in, nibble on a tentacle and provide food for both *Physalia* and *Nomeus.*

The colonial hydroids—that category of animals which are branching, with mouths along and at the end of each branch, and among whom the branching coral is probably the most familiar—and several kinds of fishes also help one another to survive. Both these fishes and these hydroids are bottom dwellers.

In such cases of symbiosis, the hydroid attaches itself to the fish. Infrequently one but usually numbers of the branched animals grow on the fish's body. Colonial hydroids have been occasionally found on scorpion fishes. In 1909 Professor Edwin C. Starks of Stanford University, dredged from the bottom of Puget Sound near Friday Harbor numbers of hydroid-bearing little sea poachers; some of the fish were covered nearly all over with their branched associates. In Bogue Sound, North Carolina, a hydroid was found attached to the back of a dorsal fin of a glut herring. The roots of its stalk went down into the fish's muscular tissue, but merely for harmless anchorage, not for parasitic absorption. Single colonial hydroids have also been found on dogfish sharks, sea horses and file fish.

Colonial hydroids go through a stage when they are tiny, and drift; in their involuntary wanderings some of them take root on fishes. Since a mature hydroid is fastened to a single spot, association with free-moving fish is a great advantage to it for the increased sources of food made available. The fish, in turn, is benefited by the camouflage provided by the hydroid; covered or partially covered by protruding branches, it looks like the bottom rocks which may also be hydroid-covered and its enemies are less likely to detect it. Of course many fish of the same species and families survive without benefit of these permanent guests affixed to their bodies; but who knows, perhaps a modification is in progress of developing and some day it will be as universal for the kinds of fishes now occasionally decorated with hydroids to be covered by them as it is now for them to have scales.

Perhaps there is also a true symbiotic relationship between the pearl fish, *Fierasfer*, and the echinoderm sea cucumber, but if so we do not know much about it. At any rate, *Fierasfer* has been observed going in and out of sea cucumbers. In the Marshall and Phoenix Islands I have frequently driven these eel-like little creatures, about as long as a pencil and not quite as big around, out of brown and blackish species of the echinoderms.

Fishes That Live Commensally

We do know that an association between certain fishes is definitely not symbiotic, but comes under the heading of commensalism—literally, eating at the same table—with the shark sucker, or remora, at the receiving end (Figure 41). This fish, three feet or less in length, attaches itself to sharks and other larger fishes by means of a suctorial disk on the dorsal surface of its head (Figure 42). The organ, a modification of a spiny dorsal fin, resembles the sole of a rubber boot in shape, flexibility and markings with transverse ridges.

At Bikini I caught several remora which attached themselves to my wet hand by suction and could be removed only by sideways sliding or by lifting the edge of the disk to let in air. I have also seen them clinging to the side of small ships.

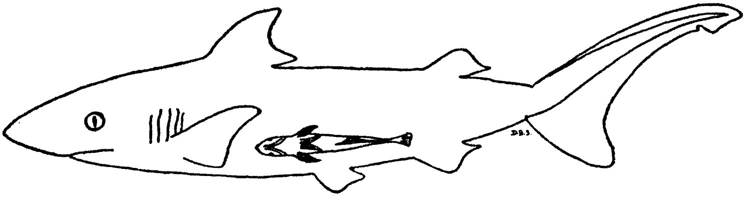

FIG. 41. The remora, or shark sucker, attaches itself to the skin of sharks or other large fishes, sharing in the "crumbs" left by the host.

When remora attach themselves to fast-swimming fishes they are secured against sliding off backwards by tiny, tailward pointing spines that project far enough from the ridges of their suctorial disks to catch firmly into the scales and skin of the fish giving them a free ride. There they stay until the larger fish's mealtime—which becomes theirs, too. As soon as there are floating bits of flesh leftovers from the chunks bitten off by the larger fish, the passenger relaxes its hold, drops off into the water and rapidly makes for them without interference by its ertswhile vehicle. After all, pieces of food that may be big enough for a shark sucker are too small for a shark, and the shark can afford to be generous.

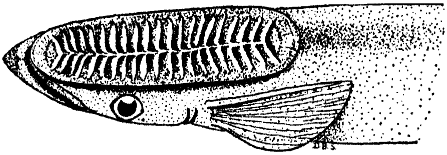

FIG. 42. The remora, by means of a sucking pad, resembling the sole of a boot, on the dorsal surface of the head, is able to hold on to its host. This sucking pad is a modified spiny dorsal fin.

Fishes That Live Inquilistically

Neither commensal nor symbiotic is the association of some fishes with mollusks. Although the fishes get protection in the shells of the mollusks, each animal eats independently. Such a relationship in which one animal houses another without getting anything in return, is called inquilinism—literally, coming and going without paying rent. Among the sojourners in mollusks is the squirrel hake which, when it is very small, seeks deep-water bottom where it hides, alone or in pairs, in the shells of giant, living scallops; specimens have been taken all the way from the coast of Maine to the Virginia capes. In the Bahama Islands, a brownish cardinal fish, about two inches long, lives in sea snails approximately the size of a man's fist; one or two tenants, sometimes a male and a female, sometimes of the same sex, have been found in the same shell. In a Marquesas atoll a different species of cheilodipterid was discovered in giant conch shells by Drs. Gudger and E. E. Reinke.

In 1922, in Delaware Bay, a seven-eighths inch long *Gobiosoma,* one of the gobies, was found embedded in the gill chamber of an oyster. Both animals were alive and healthy and neither showed the slightest ill effect from this extraordinary association, the only one of its kind ever discovered, for normally *Gobiosoma* use only empty oyster shells as their homes. That one entered a living oyster was an accident, but one of these accidents which might have great significance in natural history. Steps forward in evolution have been started off by some such accidental adaptation which turned out to be so successful that over the ages the unusual became the usual for a species. I wish I were going to live long enough to find out whether in time *Gobiosoma* and living oysters will be habitually living together, but unfortunately even with today's increasing longevity my span is mortal, and evolutionary developments take millions of years. I shall therefore have to rest content with what I know about the habits of contemporary *Gobiosoma!*

Two or three inches in length, this fish occurs in salt and brackish waters of the eastern and southern United States. Unlike many fishes it is unable to stay poised in the water or to swim easily because of its heavy body and lack of air bladder, and except for short intervals it is usually in contact with the bottom. It uses its pectoral fins to dart clumsily about with quick, jerky movements. At rest it lifts the forward part of its body and holds on to rocks by means of a suctorial organ on its underside; this is formed by its pelvic fins which are fused with the posterior and open like a grocer's scoop. Blotched brown and gray like the bottom where it lives, it feeds upon crustaceans and worms.

All about it are gaping oyster shells which make excellent hideouts and at breeding time during May and June serve as cozy nests. Each egg when laid is enclosed in a transparent, tough oval capsule, and this is cemented by one of its smaller ends to the mantle cavity, or concave inside, of an oyster shell. When a mat of closely packed capsules, measuring one or two square inches, is laid, the female goes her way and the male stays until the eggs are hatched and the young are ready to go out to find oyster shells of their own. It was doubtless at this youthfully inexperienced stage of its development that the pioneering *Gobiosoma* in Delaware Bay made the mistake of entering a living oyster instead of settling down in an empty shell as its parents and grandparents had done before it.

In some parts of Chesapeake Bay, *Gobiosoma* often occupy homes of such antiquity that the quaintest New England farmhouse into which its city-bred owner installs modern plumbing seems glaringly new in comparison. From high Miocene cliffs on the shore are washed down fossil shells millions of years old and these, as well as this year's oysters' cast-offs, are appropriated as *Gobiosoma* nests.

Another fish that associates with oysters is the pearl fish. In warm American waters, the mollusk provides a hiding place. The American Museum of Natural History has a specimen of one of these fish that was completely pearlized by its host.

Fishes That Breed in Living Mollusks

The European bitterling, *Rhodeus,* a member of the minnow family, lays eggs in mussels or clams. *Rhodeus* was introduced into the United States about 1925, and specimens have been taken in the Sawmill River, Westchester County, New York. At first it seemed dubious whether it would be able to spawn in American mussels or clams because it is adapted to reproduce only under conditions that precisely meet its requirements; however, in 1933 Dr. Breder found that it was able to breed in two kinds of American fresh-water mussels.

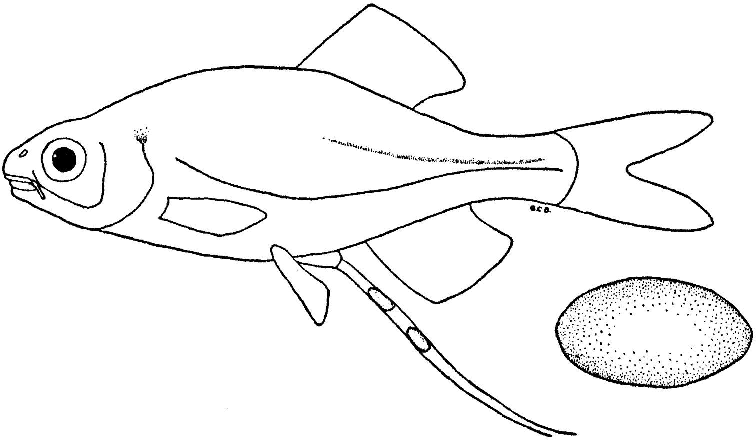

FIG. 43. The female of the carplike fish, *Acheilognathus,* of Japan, a relative of the European bitterling, *Rhodeus,* develops an ovipositor at egg laying time. This long tube is used to deposit eggs into the mantle cavity of fresh-water mussels or clams. (After Hubbs and Kuronuma.)

Asiatic relatives of the bitterling have the same type of breeding habits (Figure 43). The female possesses an ovipositor or tubular elongation which she inserts in the gill chambers of mussels. The elongate eggs she deposits are partially imbedded in the porous gills, and the larvae remain in their soft bed for a while after hatching.

Fishes That Have Parasites

As if they resented this intrusion by another kind of animal, some young mussels retaliate by being parasites upon many kinds of fishes. Some kinds of glochidia, as immature mussels are called, have an affinity only for one certain kind of fish; but others are not choosey.

Mussel embryos develop in gill brood pouches. Some glochidia escape as soon as they are hatched; others not until several months later. All, miniature mussels in appearance, are almost microscopic in size. As they are discharged from the female at irregular intervals they sink helplessly to the bottom, open and upward. If no fish comes along to whom they can attach themselves, they perish since they are unable to swim.

When a fish does swim near by the motion of the water it stirs up lifts the glochidia. Some types of glochidia have

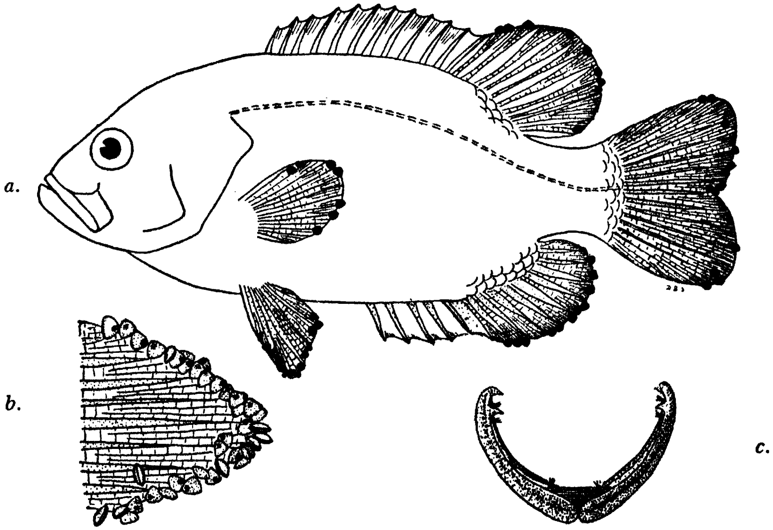

Fig. 44. During one of the stages in the life history of certain fresh-water mussels, *glochidia,* the embryonic mussel, parasitically attaches itself to the fins and gills of certain fresh-water fishes. *a.* The rockbass, *Ambloplites,* with *glochidia* attached. *b.* Enlarged section of the fin. *c.* An enlargement of one of the *glochidia* before attachment.

sharp hooks at the free edge of each part of their shells; with these the infiinitesimal creatures attach themselves to the fish's fins (Figure 44). Other types of glochidia depend upon clamping their shells to make themselves fast; these close over the fish's gill filaments. For two or three weeks to three months, depending upon the species of mussel and the temperature of the water, but at any rate until they are full-grown, the glochidia derive their nourishment from their host, who has meanwhile enclosed them in a cyst. At maturity they break out and fall down into the bottom, distributed far more advantageously than ever they could be by themselves. Although mature mussels are not immobile like glochidia, probably a fish can travel further in an hour than a mussel during its whole lifetime.

Glochidia are not the only creatures parasitic upon fishes. There is a small, worm-like coelenterate occurring in the Volga River of Russia, which develops among a small proportion of sturgeon eggs while they are still in the ovary, and as soon as the egg shell ruptures, swim forth to begin life on their own as free-swimming medusa. A medusa is all that does come out of an infected egg; no sturgeon is hatched from it, for the contents have been entirely absorbed by the parasite. Just how the coelenterate gets into the sturgeon's ovaries is not known.

Still another parasite upon fish was the colonial hydroid that Ernest Warren, Director of the Natal Museum, found attached to a fish in Durban Bay, South Africa. Finger-like projections ran down into the fish's flesh and absorbed blood.

A Fish That Is Parasitic

In the desperate struggle for existence that goes on throughout the world of living things there is even a fish that lives at the expense of members of its own family. The little catfish *Stegophilus insidiosus*—insidious cover-lover—inhabits the gill cavities of a large armored catfish, rasping the soft gill filaments with its sharp teeth and spines and drinking the blood that oozes forth. Because so many kinds of catfishes incubate their young in their mouths, it was originally thought that the smaller catfish were the offspring of the larger; but now we know that *Stegophilus insidiosus* is a true parasite like its also unpleasant relative the candiru. If it seems incredible that a fish would associate with its kindred so selfishly, we need only pause to consider whether it is unknown for a human being to live on his relatives.

What is more, certain fishes actually and actively fight their own kind.

7

FIGHTING FISHES

MOST fishes which attack—and that includes even the cannibals which do not hesitate to eat their own kind—do so for a serious, practical purpose—to get food. There are, however, a few that make assaults and fight for the fun of it, thereby having much in common with small boys. Always it is the males who are pugnacious, and never does any one of them go into combat with any but another male of the same species. After the battle, no matter how exhausted or incapitated be the vanquished, the victor does not attempt to eat him. With fishes that fight by temperament the joy of combat seems to be an end in itself.

Dr. Sunder L. Hora, Indian ichthyologist, has observed fighting between *Periophthalmodon,* one of the gobies. Adult males, confronting each other in pools at low tide, raised the front parts of their bodies as high as possible on their pectoral fins, spread their dorsal fins like sails, directed their tails upward and went to it with their teeth. A piscatorial battle of this kind observed by Dr. Hora lasted nearly five minutes; one *Periophthalmodon* caught hold of the other's pectoral fin and attempted to bite out pieces. But for all this apparent savagery the fight ended with the two fish simply separating and going their respective ways.

Second only in pugnacity to *Betta,* a fish as outstanding among the fighters as the electric eel among the generators, is *Dermogenys,* a fresh-water halfbeak that lives in quiet waters—rivers, rivulets, canals, drains, lakes and ponds—in Java, Borneo, Sumatra and the Malay Peninsula. Weighing but an ounce, they are too small to make good eating for humans; nevertheless they are useful, because mosquito larvae make good eating for them. Their chief interest for the zoologist and aquarist is their viviparity; they give birth to live young. For the sporting layman, it is the extraordinary combativeness of the males.

The Siamese, who since ancient times have liked to match small animals in contest and to lay wagers upon the outcome, get a good deal of fun out of arranged endurance contests between *Dermogenys*. Since 1863 this fish has been bred for superior techniques of attack, as race horses are bred for speed, so now cultivated *Dermogenys* are superior in strength and skill to wild members of the species and are used exclusively for man-staged contests.

Before what is the aquatic equivalent of a wrestling match, the participants are kept separately in opaque containers. The "mat" is a wide-mouthed earthenware basin, or terra cotta crock, such as are in common use in Siamese households; transparent vessels cannot be used, for *Dermogenys* tends to break off its protruding lower jaws against their sides. The vessel is filled about three-quarters full of clear water; then the two males who have been in isolation are introduced. Perhaps from opposite sides of the basin they dart at each other instantly and with great rapidity, and grasp each other by the jaws.

The usual hold observed by Dr. Hugh M. Smith is an interlocking at the base of the jaws, with bodies at right angles, but there is considerable variability in position and grasp. After generations of breeding some strains of *Dermogenys* have developed a regular specialized type of disabling clutch. One of these fishes may grasp another, without interlocking, across the base of the jaw against the tip of the long lower beak; or the hold may be oblique across the eyes or gill covers, in which case there is interference with respiration and exhaustion is hastened. At any rate, in these watery wrestling matches no holds are barred and no fouls are called, so it is doubly remarkable that serious injury is rare. About the worst that happens is that occasionally one fish jabs its jaws into the other's gill and by accident a bit of blood is drawn.

Locking and interlocking continue, with breakaways and renewals, either until one of the fish manages to maintain a hold which tires out the other, or both are no longer willing or able to lock.

Even more popular in Siam than contests between *Dermogenys* are those between *Betta,* or the "fighting fish," and no wonder. Not only does this fish merit its popular name, but its fights are more dramatic, more exciting, more prolonged and more beautiful than those of any other pugnacious fish as described by Dr. Smith. Furthermore, compared with cultivated *Betta,* cultivated *Dermogenys* are almost parvenus. They have been bred for a century for their fighting qualities, beauty and form.

Should you come upon male *Betta* in their wild state, however, you would never suspect their potentialities either as beauties or as scrappers. Three to five inches long when they are full grown, their coloring, grayish or green with faintly defined darker lateral bands, is drab. In their native waters, they are usually inconspicuous, retiring little creatures, hiding among and underneath aquatic plants for protection against the sun's glare and their enemies, fish-eating birds like egrets and herons and kingfishers. But let another male *Betta* come along and this fish becomes as excited and transformed in personality and appearance as a girl who, settled down for the evening in an old flannel robe with her hair in curl papers and cream on her face, gets an unexpected invitation from her best boy friend to go out dancing and puts on evening gown plus accessories. It spreads its fins wide; its gill membranes expand and project like a frill or ruffle that suggests the raised hackles of fighting cocks, and its entire body and fins become iridescent, a lustrous blue or reddish. Under stimulation *Betta,* even in its wild state, is one of the most beautiful of all fresh-water fishes.

Cultivated *Betta* is consistently handsome. As an aquarium species it is dark bluish iridescent black, with one dark longitudinal band running along the middle of its sides from its snout to its tail fin, another from under its eye across its gill covers thence along the base of its anal fin, and a third from the upper edge of its eye to the upper edge of its caudal peduncle. Its cheeks, the lower part of its gill covers and its scales are flecked with white; underneath it is solid white. But even this attractive everyday appearance pales besides the show that cultivated *Bettas* put on for a fight. The approach of another male, or indeed a glimpse of himself in a mirror introduced into his aquarium, causes him to burst into a glory of color.

According to Dr. Smith, who has studied the "fighting fish" in far greater detail than I have, these color phases are "intensified reds and blues, lavenders, iridescent greens, cornflower blue, blue and white, and yellowish and reddish creams with bright red fins."

The pugnacious tendencies of this fish manifest themselves at an early age; in captivity, when they are only two months old and less than half grown, the males must already be kept in separate aquaria to forestall continual scrapping. If adults as much as see one another through glass aquarium walls, they want to fight; so in order that their vitality and fighting ability will not be impaired by incessant futile efforts, their owners keep them where prospective opponents will be at least out of sight if not entirely out of mind. There are commercial stakes in maintaining *Betta* in fighting trim; contests between them have been of national importance in Siam for hundreds of years.

Most of the matched combats in which betting is involved are between domesticated fish, bred in aquaria; the wild, in captivity, may fail to show fighting spirit after a few minutes of attacking. The cultivated fight on hour after hour: Dr. Smith saw one contest go on all one day and night. There are only two kinds of intermissions, and these momentary. The first occur because of *Betta's* need to rise to the surface for air. Unlike most fishes, but like its relative the walking perch, it cannot get enough oxygen from water even in a well-aerated aquarium, and keeps mouthfuls of atmospheric air in accessory chambers. When the oxygen is used up, the expulsion of this gas and the gulping of fresh air bubbles take only a few seconds, since in this fish's wild state any excursion to the surface exposes it to fish-eating animals, particularly birds. The other type of respite comes when the fish are in sparring position, but even then by no stretch of the imagination can they be called relaxed: their fins are extended, their gill membranes expanded, an alert attitude is maintained and all their muscles are taut.

The usual method of arranging for a contest is to select two fish of the same approximate size and to place them in separate jars, where they can see each other. When they spread their fins, show their colors and make head-on attempts to attack they are removed from their containers and placed in the same glass aquarium or battery jar.

Then the fun begins. The two fighters, who have lost their excitement during the process of transference, again produce a display of color, a spreading of fins and an expansion of membranes. Then they approach each other, and their heads pointing in the same direction, take up sparring position, side by side with one slightly behind the other. Very soon they proceed to attack with movements so swift observers can scarcely distinguish the separate assaults. *Betta* does not employ the stranglehold techniques of *Dermogenys;* it fights with its teeth. This sounds more ferocious than it actually is, for this fish does not have the incisors of a shark or piranha; its teeth are small, and it nibbles, rather than bites out chunks of flesh.

The usual points of attack are the fins, sometimes all of them, sometimes with concentration on the median, the dorsal, the caudal, and the anal, or the paired pectoral or pelvic fins. Torn fins are therefore as a rule the first casualties, and as the battle goes on the fins may be reduced to mere stubs, with consequent decrease in the ability to swim, steer and balance. Single scales, or clumps of scales, may also be nipped off, or small areas of the gill covers injured. Sometimes both fish attack head on, lock each other's jaws and partially rotate on lengthwise axes by means of their taut extended fins. Such holds are rather brief, however, since the need for a literal breathing spell forces the fish to let go.

The outcome is decided not by any definite injury or "knockout blow" but by the general fatigue of one of the fish. After a while one or the other evidences a lack of desire or ability to continue the combat, and swims away when its opponent assumes the position for attack. Since the fighting is done entirely with relatively harmless little teeth, neither is "overpowered," "subdued" or "torn to pieces" as certain accounts have erroneously stated.

Winner and loser are replaced in their separate jars and the people who bet on the wrong fish pay up the luckier gamblers. At the end of a protracted contest the principals, with their mutilated fins, are not a very pretty sight, but they seem to experience no discomfort and from all evidence, with the slightest encouragement, would be ready to fight again next day. Their owners, however, will not permit them to wear themselves out so they have enforced time off until they not only feel but look as good as new. Their fins grow back in a few weeks, as our torn nails are replaced. The only serious consequences of fish fights are infections of wounds by a fungus that may fatally attack places where the scales are gone or, less often, an injured fin.

This hazard, however, is one that *Betta* and other fighting fishes which entertain men share with nearly all fresh-water fishes almost everywhere in the world; whenever and wherever a fresh-water fish has been injured, there may be the same kind of fungus infection and death. Dr. Smith has witnessed many man-arranged fights between *Betta,* and, although he is certainly every bit as much a fish lover as I am, he found nothing at all cruel about them. The rankest sentimentalist need waste no sympathy upon the fighting fish; its physical discomfort is negligible, its recovery from its minor injuries is complete, and it seems to derive great satisfaction from its particular form of sport. So does the human onlooker. Quite aside from the element of gambling, to watch the graceful movements, the agility, the alertness, the tenacity and the exquisite color displays of *Betta* in combat can be a source of pleasure to even the most squeamish souls.

Betta is not only distinctive as a fighter but also as a father, and his nesting habits are as fascinating to observe as his battling. We never had the excitement of a staged fish fight at the Smithsonian Institution, but my office was certainly disrupted during a ten-day period when we all periodically left our desks, our books and our microscopes to goggle at *Betta* leading a peaceful domestic life in aquaria.

When the male is sexually aroused at mating time, at the surface of quiet weedy waters where there are no currents or winds, he blows bubbles for the purpose of creating a nest, or hover, for eggs and newly hatched young. In achieving toughness and permanence of bubbles, this fish had an age-old scoop on the manufacturer whose long-lasting soap bub-

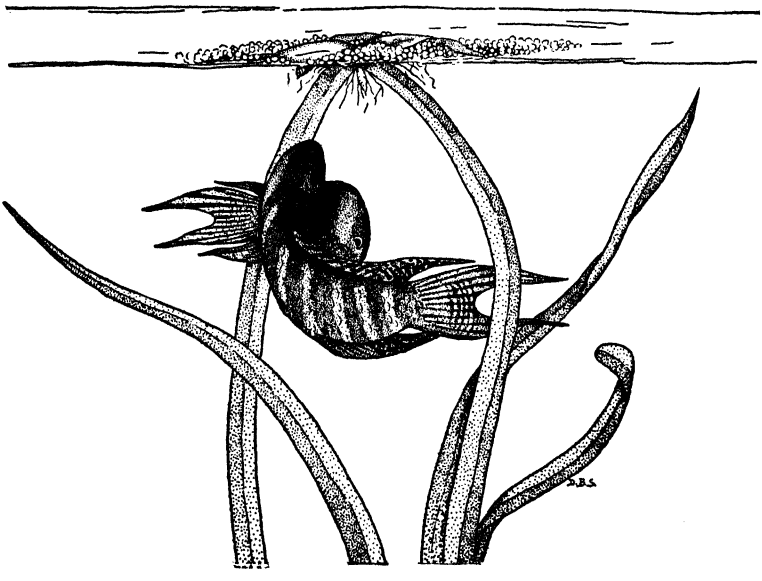

FIG. 45. The bubble nests of both the fighting fish and of the paradise fish, *Macropodus,* are similar in construction. Here the pair are about ready to lay eggs. The bubbles forming the nest are held together by their viscosity.

bles created a fad a few years ago. A viscid, mucous secretion of his pharynx and mouth makes strong bubbles that retain their contours, and it acts also as a kind of mucilage that holds them together in a compact mass to form the nest. Whenever any bubbles break or fall away, the male promptly blows new ones as replacements.

At egg-laying time the males and females mate at short intervals under the nest near the surface, and each time a few dozen minute transparent eggs are laid and fertilized (Figure 45). The eggs begin to sink to the bottom but do not reach it; immediately both male and female take them gently into their mouths and place them carefully in the bubble nest, repeating the action until all the eggs are gathered. In the hover the egg so closely resemble their surroundings that even with a magnifying glass it is almost impossible for anyone but an aquarist to distinguish them from bubbles.

When the nest contains a few hundred eggs the male viciously drives the female away; but he remains, subsisting on insect larvae, mosquitoes preferred. Because both eggs and bubbles adhere to each other, eggs generally stay put; if one does fall out now and then the male replaces it. But even if the eggs stay safe and snug they get attention from papa; he takes them, a few at a time, in his mouth and puts them back. Probably the purpose of this is to oxygenate the hover.

In water eighty degrees Fahrenheit hatching takes place in forty hours. The young remain among the sheltering bubbles while their guardian continues to give them the same kind of attention as he gave the eggs, rescuing those that fall through spaces between bubbles and giving them all their turn at getting an airing. When the fins of the young are sufficiently developed for them to swim, one strays now and then from the nest, but it is quickly picked up by the vigilant male and ejected back into where it belongs, for all the world as a parent or nurse goes after and dumps back a toddler who, eager to use his newly learned skill in walking, has broken out of his play pen or fenced-in yard.

Altogether, a *Betta* doing his paternal duties has a busy time of it. Dr. Smith has observed that in addition to maintaining the hover, replacing eggs that may have fallen out, rounding up straggling young and mouthing the eggs and young for oxygenation purposes, a male *Betta* is constantly on the alert to protect his brood from intruders who might devour them. Among these the chief offender is the mother fish who rushes at the young and tries to swallow them; all carnivorous fishes are likely to be cannibalistic when the period of parental care is over, and hers is peremptorily ended when all the eggs are in the nest. The male *Betta's* fighting habits come in very handy in the protection of the hover and when this fish lives in its natural state its defense against the mother is successful, but in an aquarium she must be removed.

If the male is eaten by a predator, or dies from natural causes during nesting time, either the eggs do not hatch or the young do not long survive; they are devoured, or their vitality is reduced for lack of bubble blowing and oxygenation, while those that settle to the bottom suffocate.

If it may seem incongruous that this scrappy, pugnacious little fellow should be such a gentle and devoted father, there is something still more surprising about his ways in captivity. Should he be put into an aquarium with the young of another pair of *Betta,* since he does not distinguish between them and his young, he takes on a foster family for which he cares as tenderly as if it were his own.

Other male fishes which take on heavy parental burdens are found among the catfishes, pipefishes and the sea horses.

8

MALES THAT INCUBATE

AMONG certain fishes the role of the sexes as we know it among humans seems to be turned topsy-turvy, and the females—even some of the live-bearers—are free of the Curse of Eve. Although, of course, they lay the eggs, it is the males who carry the coming generation in some part of their bodies for an extended period.

Fishes That Incubate in Their Mouths

Like other male salt-water catfishes occurring all over the world, the male marine gaff-topsail catfish, found in river estuaries of the American Atlantic and Gulf Coasts, carries eggs and newly hatched young in its mouth.

Although he is only about two feet long, as many as fifty-five eggs the size of marbles—later, young as long as two inches—may be fitted loosely into spaces between his gill arches and on the floor of his mouth. Naturally it is impossible for any fish to take in food with such a continuous mouthful. The young are nourished by the yolks of the eggs out of which they have been hatched, but their father is not nourished at all while he is carrying eggs and young, and he becomes a sorry sight. His normally streamlined and graceful body—common to all the sea catfishes, originally fresh-water, who have accommodated themselves to life in the sea—becomes thinner and thinner to the point of real emaciation; the floor of his mouth, depressed as much as two inches, hangs down distortedly like a dewlap, and not until the small fry leave the paternal oral shelter for the water outside does he break his fast.

The eggs of cardinal fishes are also carried in the mouths, it is reported, of both males and females, and are held safe and snug with adhesive threads binding them together. I collected some cardinal fish swimming incubators at Bikini, and found the eggs they carried developed to the stage where the larvae were already recognizable as little fish.

Fishes Whose Brood-Pouches Rupture During Births

The males of pipefishes and sea horses carry still further a prenatal process which has its similarities to gestation in female mammals. Like sexes-in-reverse kangaroos of the seas, they carry their developing young, which are born fully formed, in external abdominal brood-pouches.

Pipefishes occur in all warm and temperate oceans, and there are also some fresh-water kinds in China, India, Central America and northern South America—although the South American pipefish is the only American one known to complete its entire life cycle in fresh water Along the Pacific coast at least, their breeding season seems to extend throughout the year.

When a male pipefish reaches adult size and is ready to become a father, a darkened area develops along his underside; this subsequqently becomes somewhat grooved, and then grows flaps along its edges. More freely supplied with blood vessels than the rest of his anatomy, the flaps become swollen and puffy and ultimately unite to form a tubular-shaped bag with an opening at the front end.

The female also loses her ordinarily slim figure at mating time; her abdomen becomes distended with eggs. Thanks to Dr. Gudger's observations, we know the details of pipefishes' extraordinary mating and egg-laying. Both male and female, swimming vertically in a kind of flattened S-shape, swim past each other several times in courtship; then, with the S's reversed one upon the other and crossing in three places, they briefly intertwine (Figure 46). During the instant of contact, while the male caresses the female with his snout, she deposits a dozen or so eggs into the opening of his pouch and simultaneously he fertilizes them.

Now the male goes through some curious but purposeful calisthenics. Since the eggs are crowded into the front of his pouch and must be shaken down to its rear before there can be room for more of them, he stands nearly vertical, resting his tail fin and a small part of his tail on the bottom, and bends backwards and forwards, at the same time twisting spirally downward in corkscrew fashion. The whole routine of courtship, intertwining, egg-laying and fertilization and gyrations is repeated until the pouch is well-packed with the eggs tidily arranged on either side in sets of two or three rows apiece. Thereupon the female swims off: her parental duties are over.

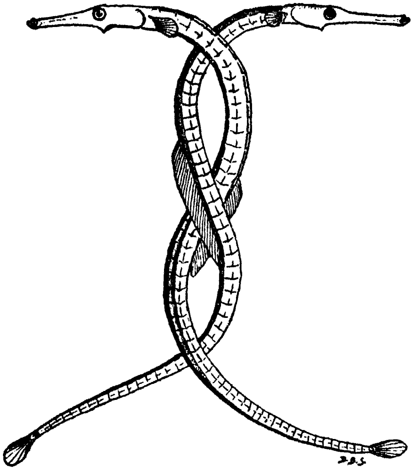

FIG. 46. During the transference of eggs into the brood-pouch of the male, the two pipefish, male and female, swim vertically together in a kind of flattened S-shape, one in reverse. (Modified after Gudger.)

The eggs begin to develop immediately the pouch is filled, and by the end of two days are firmly fastened and surrounded by vascular tissues that furnish oxygen by way of the father's blood supply. In ten days to two weeks the pouch is full of miniature pipefishes.

Now Nature performs her version of a Caesarean operation. The flaps of the pouch separate and the young pipefishes, almost as fine as a hair, swim off in the same slow motion as their parents.

All pipefishes are rather similar in appearance; long and slender, like the stem of a pipe, and covered with rings of bony plates. Their diminutive fins render them anything but speedy swimmers, so they depend upon their armor and even more upon their coloration for protection. Like chameleons, they are able to change their hues to match their surroundings; hence in coral they may be brownish or greenish, yellowish or reddish. Indeed, the collector has a difficult time spotting them. I have spent many hours searching out the little creatures among clumps of seaweed, especially eelgrass, and on coral reefs in the Pacific, where they hide among branching coral heads, in crevices, in small holes and even in sand on the reefs. Their shape, their color and their swaying movements combine to make them almost undistinguishable from plants waving slowly with the motion of the water.

In feeding as well as in swimming pipefishes keep in constant undulating movement, but they dine no more hurriedly than they travel. When they search out the tiny shrimp-like crustaceans on which they live, they assume now vertical, now horizontal positions and leisurely poke their feeble-toothed, small mouths at the end of tubular snouts, into clumps of vegetation or other likely places. As they slowly approach a prospective mouthful they seem to delay and look it over for a moment or two; then they expand their cheeks and suck in their prey.

To the crustacean items of their diet, pipefishes must seem formidably large; but by human standards they are small. Many kinds never attain a length of more than a few inches. One of the largest lives in bays of the west coast of North America, along the shores of Alaska southwestward to California. A few years ago a former student brought me an eighteen-inch long pipefish he had collected in southeastern

Alaska. It truly justified the overworked appellation "museum specimen," for it was the longest pipefish I had ever seen, or had heard of on record.

Fishes Whose Broad-Pouches Dilate

The males of some also diminutive kindred of the pipefishes, the sea horses, give birth even more dramatically and have attracted a great deal of attention because of their peculiar appearance as well as their peculiar ways. That they make sounds by moving their jaws up and down during the spawning season is perhaps the least exceptional of their breeding habits. Like male pipefishes, male sea horses also develop external abdominal pouches in which to carry the eggs, but theirs have no seams to rupture neatly at the right moment. These father fishes actually seem to undergo labor pains.

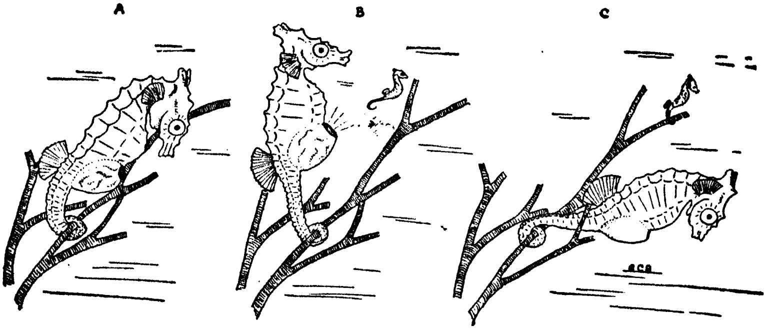

Fig. 47. The male pipefish, *Hippocampus*, when giving birth to its young, bends rapidly back and forth to aid the little ones in escaping from the kangaroo-like pouch. (After Breder.)

When it is time for the incubated young, who have been moving about in a spherical and distended paternal brood-pouch, to be born, the prospective father holds fast to a plant stem or some other object by curling around it his prehensile tail (Figure 47), more like that of a South American spider monkey than of a fish. He bends rapidly, sharply, backward and forward, as if he were suffering from severe cramps; the opening of his pouch distends and a baby sea horse pops out. With brief intervals between births the apparent pangs and jerking motions are repeated until the pouch is emptied.

Each infant sea horse emerges head first, and quite a head it has, as unique in the piscatorial world as its coiled tail. Sea horse's heads are set almost at a right angle, more like horses' heads than like fishes', which ordinarily are on a straight line with the rest of their bodies.

As if in compensation for such conspicuousness, certain sea horses of the Indo-Pacific region have camouflaging structures; fleshy flaps growing out from their bony body rings. Invariably highly colored, these flaps make excellent identity-concealers, for when they are waved among fronds

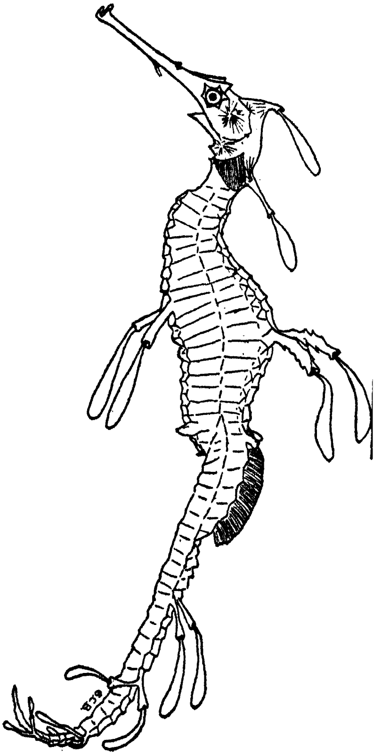

FIG. 48. The most bizarre of all seahorses is *Phyllopteryx* of the Australian region.

of sea growth they look like so much brightly colored algae or coral polyps. In the sea dragon of Australian shores, virtually perfect camouflage is attained. Most bizarre of all the sea horses is *Phyllopteryx* (leaf-wing) which, as its name indicates, has leaf-like appendages (Figure 48). With its numerous dermal cirri (skin-like little streamers) resembling fronds of algae, it is indeed a notable oddity among even its own odd kind. The postures and antics of these small fishes are grotesque and distinctive as their appearance. Not only do sea horses anchor themselves with coiled tails when they are giving birth, but at a variety of angles when they are resting. So attached, they may peer about as if they were nearsighted, occasionally rolling their eyes and adding the fantastic to the fantastic by perhaps moving each eye independently—one gazing forward and one backward at the same moment.

When a sea horse decides to go swimming after such respite and looking things over, it uncoils its tail to release its hold and, with body rigid, progresses at snail's pace through the water with constant rapid movements of its dorsal and pectoral fins. In general its feeding habits are similar to those of the pipefishes, but seemingly a sea horse always must be different; it may approach its prey on its side or even upside down, if it suits its fancy and convenience.

Its bag of tricks, big as it is, does not, however, contain some possessed by certain fishes: the ability to light up, and the even more startling ability to generate electricity.

9

ELECTRICITY AND LUMINESCENSE

A CONSIDERATION of those forms of energy, electricity and light, may seem to be more within the province of the science of physics than of ichthyology, and few laymen think of either in connection with aquatic animals. Nevertheless they play a great part in the lives and habits of some fishes.

Animate Electricity

Although man has invented machinery to generate electricity, fishes are the only living and breathing things that share this power with man's elaborate mechanisms of iron and steel. Swimming about in warm waters there are actually living dynamos. The "hows" of some fishes' amazing indeed almost fantastic, ability to generate electricity remain to a large extent a mystery. But much about the "whats" of their conducting is known, thanks to two tireless, patient researchers who, combining their respective skills in ichthyology and physics, studied *Electrophorus electricus,* the electric eel (Figure 49) and its currents. These explorers of the extraordinary ways of an extraordinary fish are C.W. Coates of the New York Aquarium and Dr. Robert T. Cox, professor of physics at New York University.

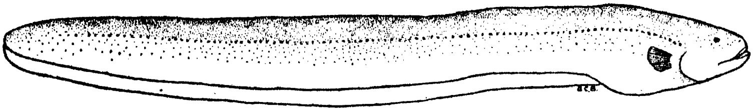

FIG. 49. The electric eel, *Electrophorus,* of South American fresh waters, gives off the most powerful electric shock of any known animal. It is strong enough to fell a mule.

The Fish with the Greatest Electric Power

The subject of their experiments is a sluggish, smoke-colored animal, occurring in shallow swamp waters of the Amazon and Orinoco Rivers of South America. It usually remains still except for leisurely, periodic excursions to the surface to gulp air; Mr. Coates found that these eels drown in about 15 minutes if they are denied access to it.

The electricity that makes this four-to-eight-foot long eel remarkable is generated (by what physiological process is not fully understood) in glands. These organs begin behind the head and extend nearly the fish's whole length, along its cylindrical body covered with smooth, scaleless skin. The skin and other tissues surrounding the organic generators are electrically conducting.

Normally the fish uses its discharges to stun other fishes which it subsequently eats. Its electric power is, however, also useful in discouraging enemies. Even should a shocked would-be attacker still be able to move, the discharge serves a purpose by frightening it off.

Although a Frenchman, J. Richer, gave an account of the electric eel as early as 1729, when Mr. Coates, over two centuries later, began his study of its discharges about all that was known was that they were strong enough to knock down and perhaps kill a horse; that they could be used at will by the fish; and that it was no safer or any more pleasant for man or beast to come into contact with them than to run into an uninsulated electric wire. Furthermore, for some time Coates' determination to discover the force and frequency of the electric eel's discharge and manner of transmission of its electricity met only with those false starts and failures that make scientific research at once so disheartening and challenging. Despite the fact that he understood not only much about fishes but also much about electricity, one after another he had to discard the various electrical measuring and recording instruments he devised. No matter how complicated or expensive they were, they would be burned out and destroyed by the electric eel's powerful current.

"Then, after four years of experimenting," Mr. Coates writes in the *Bulletin* of the New York Zoological Society published in 1939, "there came a Saturday afternoon that was the real start of our investigation. The aquarium was a maze and tangle of wires. The eel that was the subject of the experiment had been behaving badly, and the floor was liberally covered with water. So many experiments had gone wrong, and so many wires were literally at loose ends, that it was no wonder that I was tired and confused.

"Suddenly I got a terrific shock—and at the same instant a tube on the laboratory table burst into a dull orange glow! The shock was so bad that for a moment I wondered if I really had seen the tube light up, or whether it was an effect of the shock on my own system. But a chance visitor in the laboratory had seen the same thing, without feeling that shock. Here, at last, was the kind of a demonstration I had been seeking.

"Carefully I traced the connection. One wire to the neon tube dangled in the eel's tank; another had 'shorted' through my arm to the damp floor. I found that by hooking the tube to two wires, dropping their ends into the tank and tickling the eel until it discharged, I could make the tube glow any time I wanted it to—without the necessity of getting a shock!

"After several more experiments, I had sufficient information to have the General Electric Company make a sort of voltmeter for me. This was necessary because the ordinary voltmeters would not work at all or were ruined, although I did not know why. . . ."

His next step was to enlist the co-operation of Dr. Cox. The chief instrument the two scientists developed, and are still using in continued work on the electric discharges of fishes, was the cathode-ray oscillograph which, when connected by wires along the underside and dorsal surface of an electric fish, traces on a screen the impulses fed into it. These can be photographed and subsequently compared with recordings of electric impulses of established values.

Thus it was found that although voltage varies with each individual eel, the average-sized one discharges about 550 volts. An eel about a yard long attains maximum voltage, 450 to 600 volts; some electric eels run as much as eight feet, but without appreciable increase in voltage, albeit there is greater power. A small specimen, only about nine and a half inches long, had a voltage of 198; this dropped to 136 after a few hours of repeated discharge.

The impulse travels along the eel's body at a prodigious rate —usually between 1640 and 3936 feet per second, although as high as 4920 feet per second are on record. This is twelve to fifteen times faster than the impulses travel along human nerves to and from the brain.

Wattage, the experimenters found, was about forty. "But," reports Mr. Coates, "we can draw almost one thousand watts without disturbing the fish in the least. . . .

"We are not surprised when people question our statements," he goes on to say, "nor do we feel unduly put out when they doubt them. After all, it is somewhat in the nature of a fish story to say that a fish four feet long and about five or six inches in diameter has a power pick-up several times that of an ordinary automobile—and yet that is just what this electric eel has! To reduce it to figures, any average electric eel of three feet or longer has a power pick-up of about 150 horsepower per second, a fact which seems to belong in the 'Believe It or Not' class. . . .

". . . The point is that while the fish has this power and releases it whenever it wishes . . . the speed with which it is released is so fast that the ordinary available kind of machinery is quite unable to respond before the impulse is gone. This can be explained most simply by the example of ordinary incandescent lamps.

"In this part of the world, the electric current supplied for household use is 110 volts, and a standard electric lamp is, say, 60 watts. We have drawn from an electric eel almost

600 volts and about 1000 watts, which is obviously enough to light a great many of these standard electric light bulbs. However, the eel cannot light any of them because the inertia of an ordinary electric lamp takes about one-fifteenth of a second to overcome, while the discharge of the electric eel, although it is so much greater than that required to light the lamps, is passed and gone in about two one-thousandths of a second, or in about one-tenth of the time it takes the lamp to light. If the lamp, by any accident ever did light the filament would be burned out instantly."

Other Fishes with Electric Power

To some degree, electric discharges are also known to exist in the Mormyrid eel of African fresh waters and the marine fish *Uranoscopus* (star-gazer); and, to a slightly stronger one than in these fishes, in the African fresh-water catfish, *Malapterurus* (Figure 50).

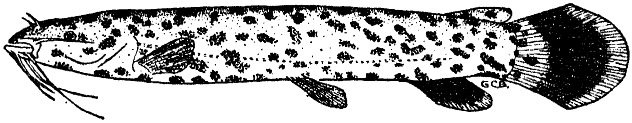

FIG. 50. The electric catfish, *Malapterurus,* of Africa, gives off a strong electric shock.

Second in power to the more spectacular eels are the electric rays which occur along the Florida coast and in the West Indies. They are shaped much like their relatives the stingrays—disk-like, with short tails—but instead of being poisonous their defensive equipment is electrical. This is sufficient to make even tough commercial fishermen leery of being shocked; when electric rays are caught in nets they are left strictly alone until they are dead and safe to handle.

Like many rays, *Narcine* (Figure 51), one of the electric members of the family, gives birth to live young, four to fifteen in a brood and, when such infants are touched, they retaliate with feeble little shocks. Indeed, even "incubator babies" of this fish are already all set up to generate and transmit currents. Dr. Breder once caught a female *Narcine* and upon his placing her in a bucket she gave birth prematurely. When he reached his hand into the bucket and scooped up some of the newborn mites, he dropped them in surprise. They had let him know unmistakably, that maybe they were tiny and premature, but for all that they *were* electric rays!

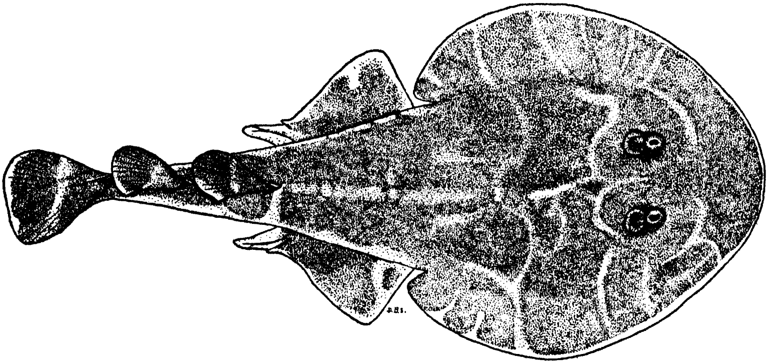

FIG. 51. The electric ray, *Narcine,* gives off a strong electric shock. It has been able to solve the problem of electric discharge and insulation in salt water.

Another kind of electric ray is the torpedo, found in shore waters of the Atlantic and Pacific Oceans, occasionally as far north as Long Island and Puget Sound in one hemisphere and as far south as Argentina in the other. Its usual coloring is grayish and brown with pale specks above, whitish underneath; it may reach a weight of 150 pounds. The electric organs, behind the head and at each side, are gelatinous glands, hexagonally compartmented like a honeycomb. My first meeting with a torpedo was in Puget Sound, where it occurs as a tourist. I wish that I could give an exciting, hair-raising account of what happened when the fish was lifted in a shrimp trawler's net into the boat in which I was a passenger, but I must be truthful. Having been jostled in the dragged net for nearly an hour, it was too exhausted to give a performance.

Livelier specimens of the torpedo were connected with Coates and Cox's oscillograph and their electromotive force was shown to be 220 volts. After about a one-minute period, during which discharges occurred at intervals of one thousandth of a second, the charge dropped to 60 volts. Both the right and left electric organs discharged simultaneously, and a small amount of muscular activity was evidenced by distinct tremors and a slight upward curling of the ray's wings (outer edges of the body).

Right now, there is no hope for any of us that by maintaining an aquarium full of even the most powerful electric eels we might be able to do away with paying bills for the electricity we use. To date no way has been found to harness the power of electric fishes, nor, as far as I know, is anyone working on the practical application of this unusual form of animal energy. To the pure scientist learning new facts, finding out the truth, adding to the store of human knowledge, are ends in themselves. Still, I cannot keep myself from daydreaming about the potential role the electric fishes might someday be playing in everyday life. Granted that such speculation, in our present state of knowledge is farfetched, would it not have been equally fanciful to envision the manifold twentieth century uses of electricity at the time when Benjamin Franklin flew his famous kite?

Animate Light

Although to the best of my knowledge my favorite animals have the distinction of being the only ones to produce electricity, I cannot claim that they are unique in the possession of another uncanny ability. Throughout the natural world various kinds of creatures, in addition to fishes, give forth strange, heatless lights.

There are, for instance, luminescent bacteria. Once, when I was a small boy, during a severe thunderstorm a tree on our farm was blown down and where the trunk had been split there was an eerie glow. My mother called it "fox fire" and said it came from rotten wood's having become rainsoaked. A day or so later I went to the wreck of the tree, broke off several pieces of the magical wood and placed them in water, convinced that if I kept them forever wet they would forever glow. The dead wood remained simply dead wood, and I never confided my disappointment in anyone, for fear of being thought foolish, so it was a long time before I had the explanation of what had happened; that the luminescence had been caused by bacteria, which died.

Far away from Albion, Michigan, in both miles and years, I again encountered something like "fox fire," this time in connection with fishes. One afternoon when I was collecting on Rose Island in the South Pacific, I acquired so many big-eyed scads and other fishes that I could not get them all preserved that night. I placed the unpreserved specimens, together with the severed heads of the scads we had eaten for dinner, about twenty yards from my cot and turned in. At about two o'clock in the morning I was awakened by the screeches of terns. As if the sound they made was not weird enough, a sight still weirder greeted my sleepy, startled eyes; all the fishes and all the heads were glowing brightly. One gets the feeling in the South Pacific that almost anything can happen; so not until I was fully awake did I realize that bacteria as well as dead fishes, not ghosts, had become my camp-mates.

Again, when I was walking along the shores of Tuituila Island, I created waves of light underfoot. Each time I took a step in the coral gravel the vibration stirred up countless shining organisms, invisible to the naked eye as separate units.

Also, living sparks dance through the air. In the eastern parts of North America and in Asia, fireflies flitting brightly create endless delight for children who make a game of catching "fire" without getting burned. These insects, in their larval stage, are known as glowworms which are often seen crawling along lake shores and in the grass of back yards. "Glow little glowworm, glimmer" was the opening phrase of the chorus of *The Glowworm,* a 1905 popular song.

When I was in Venezuela I encountered another luminescent insect which has not, as far as I know, been celebrated in song. Trying to while away the dull, dark period after sundown, too far away from a stream where I could catch more fish, I sat on my cot on a little rocky promontory and read with the aid of a flashlight. Some buzzing wasps came towards the light, and I grabbed my forceps and collecting bottle. (I always have such apparatus handy when I am collecting fishes in little-traveled regions, for the hearts of certain of my colleagues at the Smithsonian are as gladdened by the gift of a specimen of some rare or hitherto unknown insect or crustacean as mine is by that of an unfamiliar fish.) In my haste I dropped the flashlight and it went out. But even in the blackness I was able to pick up three of the wasps with my forceps, for their abdomens glowed, and indeed continued to glow for a short time even after I had dropped the insects into the preservative.

All temperate and tropical seas contain numbers of small luminescent marine organisms visible as spots of light near shores and in the waters that break alongside and in the wake of a ship. Among them are microscopic bacteria and protozoans, jelly fishes, ctenophores—another kind of jelly-like animal about the size of a walnut—and shrimps. Unlike the incandescence of an electric light, where the glow is produced by heat, the luminescence of living creatures is the result of chemical action; the oxidization of a secretion produced in their bodies.

The Luminescence of Fishes

Practically all the deep-sea fishes, those living at depths of 300 to 1800 feet, are luminescent, and some others in still deeper waters. Fishes' light-producing organs, or photophors, are numerous in kind, varied, and different in origin, but the most general type is composed of glandular cells in the skin. These manufacture a secretion which oxidizes and glows when it unites with oxygen in the fish's blood. Usually the photophors are associated with some kind of lens and reflector that concentrate the light.

All luminescent fishes have their lighting systems under voluntary control; by some mechanism not fully understood, they can turn them on and off as easily as we humans manipulate an electric light switch. Fishes light up for various purposes: to attract food or mates, to identify themselves to their own kind in the dark, or as a defense. Some fishes, like those infuriating drivers who blind you with bright oncoming headlights, flash dazingly to confuse and divert enemies coming towards them. The fishes' use of their lights makes the better sense.

The Lighting Devices of Some Fishes

The Stomiatidae, or wide mouth family, usually have two rows of photophors along each lower side of their bodies; swimming, they look like moving ships with lighted portholes. The Myctophidae, or lantern fishes, some of them deep-sea and some not, are dotted with shining bits like reflector road signs (Figure 52). One of the berycoid fish family, the *Anomalops*, occurring in the Indian Ocean, has only one luminous organ but that, as the teenagers say, is particularly "neat." Located below the eye, it is attached to a movable flap or stalk. Below the eye, too, there is a small cavity. When *Anomalops* wants to douse its light, it curls it up then tucks it into this convenient little pocket.

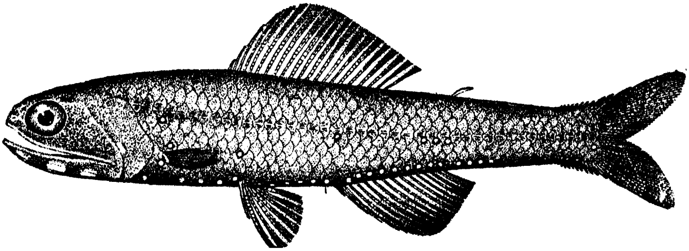

FIG. 52. The lantern fishes, Myctophidae, have luminescent organs in groups. They occur in nearly all seas. Some species, coming to the surface at night, are attracted to a light and may be picked up with a dip net.

Some deep-sea angler fishes have bulb-like fleshy luminous tentacles dangling below their chins. Others carry their bulbs at the tips of their fishing rods. One of these is in the interesting family Ceratiidae.

A Fish That Lights for Two

At the beginning of this century ichthyologists recognized, among others, two distinct families of deep-sea angler fishes, respectively called Ceratiidae and Aceratiidae. Then, one day eventful for science, the late Mr. C. Tate Regan, head keeper of the British Museum, discovered one of the Aceratiidae hanging on to the side of a female of the Ceratiidae; its jaws had taken firm hold of her skin (Figure 53). Many similar pairings, subsequently observed, plus the fact that no females have ever been found in the Aceratiidae, led to only one possible conclusion; that the Aceratiidae and Ceratiidae were not two families at all, but one and the same, with the Aceratiidae actually the males of the Ceratiidae.

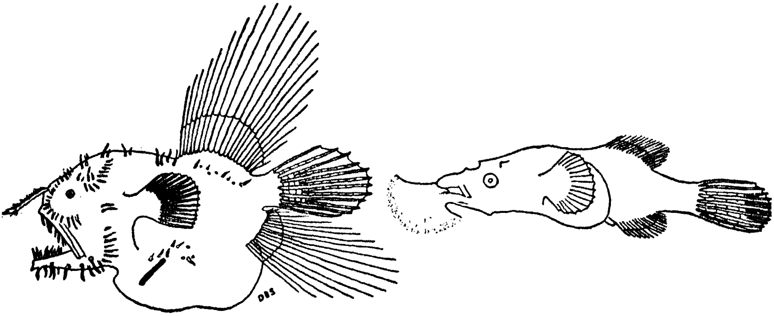

FIG. 53. The female Ceratiid has the male (black) attached below the pectoral fin. On the right is an enlargement of the male. (After Regan.)

Unattached males that have been caught were only two inches or less in length, one fourth of this tail; males attached to females were three-quarters of an inch to four and a half inches. The females to whom the males were fastened so fast that their snouts actually grew right into their mates' skin were much larger, two and a half to forty inches. But difference in size was not the only feature which misled earlier ichthyologists into classification into separate families. The females have fishing rods attached to the front of their heads and at the tip of the rods are luminous bulbs. The males have no externally visible rods; theirs, reduced and shortened, it has been found upon dissection, are embedded in their skin. Furthermore their jaws are longer than the females' and modified into a pincers-like structure adapted for getting a good hold.

This attachment of the male Ceratiidae to the females seems superficially like parasitism, especially because the males' digestive systems are degenerate (not used). However, there is no conclusive evidence that the males receive nourishment from the females who carry them about. Rather, it is believed, the attachment is a form of prolonged mating.

Dr. A. E. Parr, Director of the American Museum of Natural History, has presented the theory that the object of the light, or lure, at the end of the female's rod, is to attract the male, and this seems highly probable. In the deep dark waters where the Ceratiidae live, two fishes might unknowingly pass within a few inches of each other without some kind of beacon.

A Fish That Glows and Sings

The luminescent fish, *Porichthys notatus,* a kind of toadfish, lives along the western Pacific Coast from Alaska to Mexico in shallow water near shores and to depths of four

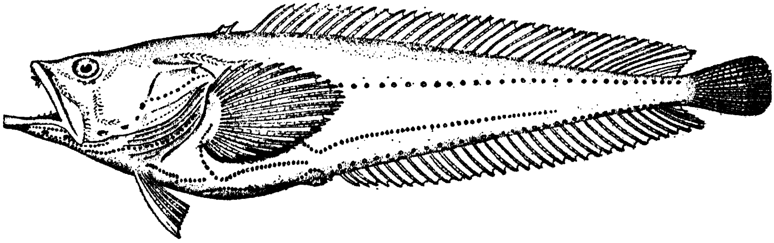

FIG. 54. The toadfish, *Porichthys,* of the Pacific coast from Alaska to Mexico, lives near shore. It is called the singing fish because during the breeding season it can be heard humming.

hundred feet (Figure 54). Unlighted, which it normally is, it is not especially distinguished looking; it is dull brownish with dark transverse stripes above and whitish underneath. But when *Porichthys* is irritated or excited, it justifies its popular name of the midshipman, for then it sports rows of shining buttons—many series of lights that extend from head to tail along its sides.

Still another name for this fish is the singing fish. It breeds in tidal pools, cementing its amber-colored eggs to the tops of crevices or overlying rocks. As with most fishes, the male guards eggs, nest and young. But unlike most fishes, this one is able to make itself heard while it is on sentry duty. Throughout the breeding season, at night and during early morning and evening, it makes a humming sound when it is disturbed.

Although *Porichthys* is one of the few fishes that have both a light-making and a sound-making apparatus, hundreds are equipped with the latter.

10

SOUND AND SIGHT

Fishes That Make Sounds

MANY people are surprised when they learn that fishes can express themselves in sound, and I believe the reason is not only because their gruntings and croakings are less familiar in everyday life than, for example, the barking of dogs or the chirping of birds, but also because one is inclined to think of them primarily as quite silent creatures. Indeed, the inaudibility of their movements in water is the envy of engineers, who have never been able to devise, for traveling speedily through water, any mechanism as quiet as a swimming fish. Withal, there are some fishes able to talk to one another during the breeding season, to make noises to frighten away enemies, or to make known their discomfort or fear.

Fishes produce various sounds in various ways. One of them is grunting by the expulsion of air through a duct leading to the air bladder and, usually, connecting with the mouth, although one of the loaches which occurs in Asia expels the air, and consequently makes the sound, through its anus. When I was in Venezuela collecting fishes, before my net, which I had dropped into a fairly large stream, was out of the water, I could hear peculiar sounds something between a grunt and a bark. After the net, which contained a number of ten-inch-long *Pimelodus,* a kind of catfish, had been pulled on shore, the noise could be heard many yards away.

Certain sculpins employ stridulation, that is, the friction of one surface against another, to produce sounds. When they vibrate their gill covers against the sides of their heads, humming ensues. The horse mackerel, the ocean sunfish and certain trigger fishes use their pharyngeal teeth, which lie far back in their throats, for stridulation; ground together, these make a grating noise. The grunts, a tropical shore fish, when in difficulty and sometimes on other occasions, use their pharyngeal teeth similarly to make loud rasping croaks. Even inch-long grunts have the gift of self-expression and vindicate the family name.

When a grunt is held with its mouth open, its upper and lower pharyngeal teeth may be seen to grate against one another, the rear edge of the bony lower part abutting against the front edge of the air bladder. Both the air bladder and the teeth are necessary for the production of this fish's characteristic sounds. When Mr. Burkenroad of Tulane University deflated the air bladder of a dead grunt and scratched its teeth with a metallic instrument only a dry rasping occurred, but with the air bladder inflated there was the normal grunting. However, when he placed a piece of cloth between the teeth of a living grunt, although it tried to make itself heard, and its body vibrated with the effort, there was only silence.

The hogfish, one of the grunts, by gnashing its pharyngeal teeth makes a harsh rasping noise that comes in bursts of four or five rasps in quick succession.

The sea robin, too, makes a grunting sound, although this is produced by a quite different mechanism—special muscles in the air bladder. M. B. Dobrin of the Naval Ordnance Laboratory, Washington, D. C., says that most people would associate the rhythmic squawks, squeals and cackles of the sea robin more with a barnyard than with the sea. Another noise of the same derivation is made by the toadfish, *Opsanus.* It consists of an intermittent, low-pitched blast like that of a boat whistle, only half a second's duration at a time but persistent. Although no toadfish would ever oblige with sound in captivity, one, in one instance, kept up its soundoffs for days at a time. Of all the forms of marine life investigated along the Atlantic coast, Dobrin stated that this fish made the most intense noise.

Any finny orchestra would have its quota of drummers. Some trigger fishes, just behind their pectoral fins and above their air bladders, have a taut membrane. When they move the fins rapidly back and forth the fin rays act as drumsticks and strike upon the membrane; this vibrates and acts as a resonator for the underlying air bladder exactly like the skin of a drum.

In open water, the croaker probably makes more noise than any other kind of fish. One day, when I was on an oil barge anchored in Lake Maracaibo, I could hear croakers thirty feet down. Bursts of rapid drum-rolls, two or three beats, sounding very much like a muffled electric drill in pavement, are produced by the action of special muscles on the air bladder.

Certain South American catfishes growl and hum by means of an elaborate mechanism. Their air bladders are divided by membranes into many sections. Their first four vertebrae are modified into elastic springs. Like a cap, one end of the spring fits into the end of the air bladder nearest the fish's head; the other is attached to strong muscles reaching to the rear of the skull. These fishes "speak" by vibrating spring and muscles; the air bladder resounds and its numerous partitions act as amplifiers. *Galeichthys,* one of these catfishes, in addition to a rhythmic drumming noise like the beating of a tom-tom produced in this fashion, makes a mewing sound by way of stridulation. It has a movable pectoral spine that locks in a forward position for defense when the fish rotates it counterclockwise a bit. The locking process is quiet; but apparently clockwise unlocking engenders creaks.

Naval men have more than an academic interest in underwater sounds. The various noises made by fishes in bays, in gulfs and at sea, as well as the snapping and crackling of shrimps, at first threw submarine detection into confusion. Ultimately phonographic records were made of the sounds produced by fishes in various parts of the world, so that military men at instruments could identify them for what they were.

The Hearing of Fishes

Fishes themselves are able to recognize quite well the sounds made by their own kind, for they can hear in water. Many years ago Dr. G. H. Parker, professor of zoology at Harvard University, established this fact; also that they react to sounds, retreating from those that disturb them. Most sounds occurring in the air, even loud ones such as shots, are not transmitted into water with sufficient intensity to stimulate fishes; but if an explosion occurs under water they are profoundly affected.

Unlike humans and other mammals, fishes have no external ears to act as funnels for sound waves, but they do not need any, for vibrations are carried with greater intensity in water than in air. They do, however, have internal ears as complex as ours.

In all fishes low frequency vibrations in water are conducted through the ear by an auxiliary group of auditory organs. There is a system of pores that extend through the skin and scales and are visible as slight surface elevations. Underneath the skin minute tubes connect these pores, whose number and arrangement vary. Certain fishes have as many as five rows of them; in others branch lines of pores may encircle the body. On the head, tubes and pores are called cephalic; along the fish's sides, lateral line. The entire cephalic and lateral line systems are abundantly supplied with tiny organs having sensitive nerve endings that, together with the nerves from the ear, register and carry to the brain the sensations of sound that result when waves, or objects falling or moving, stir up vibrations in the water. This sensitive, complex receiving system of fishes reacts exclusively to sound; not light or heat or chemicals or food or foulness of water or water pressure or currents affect it.

For purposes of food procurement or defense the hearing apparatus of fishes serves them as well as do their electricity, luminescence, barbels, fin rays or any other of their special adaptations. Their eyes, too, are suited to their needs.

The Vision of Fishes

Albeit with some minor differences, in general the eyes of the great majority of fishes are very much like ours. They have an outer covering, the cornea; a colored curtain, the iris, brown, gray, hazel or blue with us—red, blue, green, yellowish or brown with fishes; a pupil through which light passes; and a crystalline lens, more spherical in fishes than in mammals. The more pronounced sphericality makes for nearsightedness, but this is no handicap to fishes since water is somewhat turbid at best and they could not see great distances in it even if they had the equipment to do so. One of the most stupendous steps in the whole evolutionary change from fish to land vertebrates occurred when fishes living in drying up pools of Devonian times adapted themselves to life on land. Fishes with the usual nearsighted eyes, adequate for living in water, had among other modifications to transform their eyes so that they could accurately see objects at a greater distance; their large spherical lenses had to be flattened, reduced in size, and moved back from the cornea in order to focus the image accurately on the retina.

Normal fish eyes have no tear glands to moisten them; obviously such organs are unnecessary. Nor do most fishes have eyelids; these too are not essential for protection and to keep the surface moist and clean, as they are in the air. However, enough fishes do have eyelids to keep their eyes in the category of the normal. Fishes' eyelids are of two general types, neither of which closes down over the eyes like our own. Certain ones have adipose eyelids, a fixed gelatinous growth partially covering the eye and containing a circular opening through which light passes. Others of the more primitive type like the sharks have the same kind of eyelids as frogs. These are called nictitating membranes; they go up from the lower part of the eye and are movable.

Nearly all fishes living near the surface have the usual kind of eyes. The eyes of most of those occurring in depths of from 300 to 1500 feet are large and modified to pick up every faint ray of light that may penetrate the dimness. Below 1600-1800 feet eyes are imperfectly developed or small, as are luminous organs in general, in these parts of the waters. In the abysmal depths there is a group of fishes, the grenadiers or rattails, which have well-developed eyes but none or only feebly developed luminous organs. It is supposed that they use their eyes to feed on luminous bottom invertebrates.

Fishes with Eyes Unusually Placed

Although one can generalize about structures common to certain animals, there are few forms in nature that do not have their exceptions, and some rarely encountered fishes have peculiar and distinctive eyes. Those of the Oceanic Giganturidae, for example, are telescopic, attached to the front end of protruding cylinders which can be directed forward and upward, like the stalked eyes of a crab. Also telescopic are the eyes of *Opisthoproctus,* but these can be directed only upward as the cylinder is fixed. The young *Stylophthalmus* have their eyes at the end of long delicate stalks growing out from the sides of their heads; at maturity these stalks retract and the eyes of mature *Stylophthalmus* are normal. I wish I could give more detail about these three fishes with such pecularily located eyes, but unfortunately not much is known about their ways.

Fishes That Can See in Air

Two kinds of fishes, *Dialommus fuscus,* one of the blennies, and *Anableps,* are loosely called "four-eyed"; actually each of them has only one pair of eyes but since each eye is divided into two distinct units, one for seeing in air and one for seeing in water, the inaccuracy is not too unjustifiable.

The late Dr. H. Walton Clark, one time Curator of Fishes, California Academy of Sciences, has given an account of *Dialommus fuscus* in the Galapagos Islands (Figure 55). The first example of one that he noticed was: ". . . on top of a rock along the shore of Wreck Bay, Chatham Island. It looked very much like a curled up salamander, with black, smooth, glistening skin and prominent, beady, watchful eyes." When Dr. Clark approached the creature with a dip-net, it plunged into the water, and not until he had seen many other similar little animals spring from rocks into the sea was he certain they were fish and not amphibians.

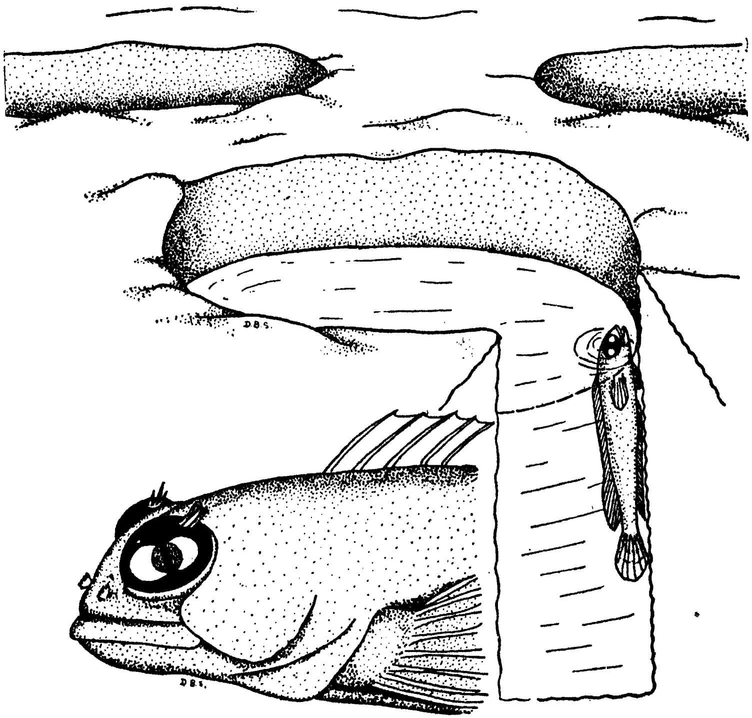

FIG. 55. The four-eyed blenny, *Dialommus,* in a natural position in a pothole in a reef. Lower left, enlargement of head of *Dialommus,* showing the nature of the "four eyes."

The ability of *Dialommus fuscus* to make quick getaways, its alertness and elusiveness and the spots on which it chooses to be, make specimens scarce in museums. Dr. Clark concluded: "They seem to be neither ocean nor tide pool fishes but rather pothole inhabitants, living with the suckfishes, in deep depressions back some distance from all but the highest tides." So well adapted are they to climbing the steep vertical walls of potholes that they managed to ascend even the smooth sides of Dr. Clark's enamel collecting can.

Each eye is divided by a vertical septum, evident as a dark line running across the corneal surface. This is probably a modification of the umbulacrum, a little flap of iris like an eyeshade, that covers part of the pupil in many kinds of both marine and fresh-water fishes of families that live exposed to tropical sunshine. In the four-eyed blenny it is likely that the flap grew down until it fused with the lower part of the eye. Close examination shows that the pigmented areas or opaque surfaces of the eye lie before and behind the dividing line, and each has a circular opening, about one third of the diameter of the pigmented part, through which light passes to a crystalline lens, spherical as in most fishes. The structure of the eyes is not fully understood, but anyone who attempts to collect this fish finds plenty of evidence that it is able to see both in water and in air. Its lenses seem to be somewhat movable, backward and forward, and thus to be adjustable for aerial or aquatic vision. This is interesting; that it can see in air and water simultaneously is remarkable. Dr. Breder thinks that when this fish stands vertically in a pothole with the forepart of its head above the water, as it does much of the time, the water's edge passes across the dividing septum exactly between the paired corneal areas. The half of the eye thus underwater sees at the same time as the half in the air.

The only other known fish to have divided eyes is the four-eyed fish, or cuatro-ojos, or *Anableps,* which occurs in southeastern Mexican fresh waters to northern South America at least down into the Guianas (Figure 56). Its eyes are divided not vertically but horizontally. Swimming almost constantly at the surface, its upper aerial eye sections focus horizontally and obliquely upward a little, while the lower aquatic sections look obliquely downward into the water. Humans who must wear bifocal spectacles would feel themselves fortunate if, like *Anableps,* the two parts of their aids to vision were a structural part of them and hence unlosable and unbreakable.

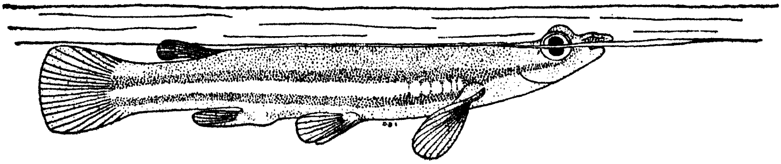

FIG. 56. The four-eyed fish, *Anableps,* of Central and South America. A normal pose is at the surface of the water, where it looks with the "upper eye" into the air and with the "lower eye" into the water.

Anableps is ordinarily five to seven inches long, although it sometimes attains a length of one foot. It has specialized in feeding on floating tidbits which it encounters as it swims along the surface and is able to see with the aerial parts of its eyes. Its habit of jumping and leaping when it is disturbed makes capture difficult. Nighttime is best for collecting it as then it can be blinded with a torch and caught with a cast net. Although this fish has been known for 150 years, little is on record about its life history.

There have, however, been numerous observations on its

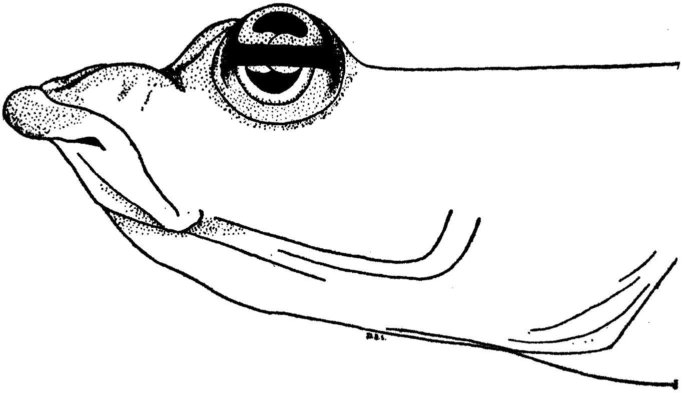

FIG. 57. An enlargement of the eye of the four-eyed fish showing the nature of the eye.

eyes. They are rather bulging. As with *Dialommus fuscus*, each has only one lens, but this is especially adapted for its double duty. Egg-shaped, the long axis is directed into the water, the short into the air. The lower pupil is shielded by a double shade formed by projecting parts of the iris and apparently can be expanded and contracted to cut out surface reflections from above; these might blind the fish or obstruct its view in the water.

The way *Anableps* meets what seems like an insoluble ocular problem appears more marvelous to me than many a much-touted instance of man's ingenuity, when he lacked special equipment, to adapt himself to various conditions. In the air eyes have need of protection and need of being kept moist; for this eyelids and tear glands serve the human eye. However, though *Anableps* lacks both these special devices, as a surface dweller it must keep the parts of its eyes used for aerial vision moist while at the same time it cannot afford to give up its aquatic vision, necessary to give warning of enemies coming from below. Here, apparently, is something as difficult to resolve as to have your cake and eat it. Yet *Anableps* manages to turn the trick. Every few moments, it dips its head under water.

Fishes That Are Blind

Some fishes cannot see at all; even so they are not handicapped when it comes to food-getting. Just as other senses of man become more acute when he has no eyesight, so does Nature compensate blind fishes (for whom vision would be of little or no use anyway where no light penetrates) with special devices that enable them to get food. Among these are well-developed barbels and sensitive sensory pores with dermal cirri (short hair-like filaments).

A few of the eyeless fishes live in the depths of the ocean; most in the waters of limestone caves or in cracks and burrows that are like caves in miniature. In such enviroments there is little competition and the fishes survive. There are also but few of the regular changes to which most organisms have to adapt themselves. The abysmal depths of the seas do not alter from day to night, from season to season, from year to year or from eon to eon. In caves diurnal changes are practically nil and seasonal slight; about the only variations in such waters occur when the caves are flooded and currents, depth and, above all, clarity are somewhat affected.

It is interesting to speculate whether down through the generations the sightless cave dwellers lost their eyes after they had taken up their monotonous and peaceful subterranean lives or, conversely, whether they moved into their sheltered surroundings because they were blind. Still another guess has it that radioactivity in long past ages caused the mutation of the disappearance of organs of sight.

Although any of these interpretations make sense I rather lean to the idea that cave-dwelling fishes lost their eyes—some of them have nothing more than a bit of pigment remaining where eyes ordinarily occur—after they had made their move into the darkness and organs of vision became superfluous. First, all but one of the fishes that have become actually blind are those that had a tendency to having small and reduced eyes. Second, the relatives of all the cave dwellers, with one exception, are pre-adapted to life without light; either they have nocturnal or burrowing habits or they seek crevices, or, as in the catfishes, they have highly developed tactile organs that enable them to get food without actually having to see it. Thus it is not at all difficult to predict which fish families are likely to have blind relatives.

The one exception, the blind characin, *Anoptichys,* a Mexican cave fish obviously derived from a free-swimming open-water form without any special sensory organs or habits, indicates that almost any fresh-water fish may have the capacity to become blind if conditions, such as a long period of time and lack of competition are suitable.

Dr. Hubbs has listed sixteen families of eyeless fishes exclusive of deep-sea fishes with blind or nearly blind relatives, and among these families are twenty-nine species without any external evidence of eyes that could possibly be used for seeing during adulthood. In certain blind fishes the eye begins to develop in the normal way in the embryo, but when they are very young it lags behind the other structures in its rate of growth, ultimately ceasing altogether to grow. Some parts, usually the lenses, become arrested sooner than others. Shortly afterwards even what there is of the eye actually begins to disappear, until it is gone altogether.

No such peculiarities of organs or development characterize certain other fishes even more noteworthy for something else: their unusual spawning habits.

11

OCEAN BEACH SPAWNERS

QUITE as marvelous and mysterious as the space and place instinct of eels, which leads them year after year, generation after generation, to cover thousands of miles of ocean and reproduce in the same areas, is the time-and-tide instinct of certain fishes. Grunions and some smelts spawn by the tides with a fixed regularity and nice timing unexcelled by man's crack trains.

A Fish That Leaves Its Eggs on Dry Land

Among these followers of the tides the most spectacular in its spawning habits is the grunion, practically the only kind of fish known along North American shores that comes out of the sea to mate and lay its eggs in the sand of beaches.

This five-to-seven-inch-long fish, bearing a general resemblance to the silver smelt with its dusky back and its silvery body black-banded lengthwise along the sides, is peculiarly limited in habitat, for it occurs nowhere except along the southern California coast from Point Conception southward to the northern part of Lower California. Indeed, even within this circumscribed range it has its favorite spawning spots—Long Beach and Belmont Shore, southward to Huntington Beach and near La Jolla—and spends its entire life near them. With the whole southern California coast from which to choose, why the grunion prefers to use certain beaches for its spawning grounds, rather than others seemingly just like them is as inexplicable as why people flock to certain resorts while others in the same region are unfashionable and deserted. Once it was thought that grunions, like the Pacific salmon, have a homing instinct, but that was disproved during June and July, 1928, when grunion began to run on a new artificial beach that had been built at the base of the breakwater in Los Angeles harbor in 1927.

At any rate, on certain nights from March to August, at predictable long, sandy beaches at equally predictable times, grunion come in by the thousands as each wave breaks, swim up the gently sloping beach with the wash of the wave, squirm for a few moments in the thin sheet of water and flop back into the sea with the wash of the next wave. Crowds of residents, tourists and picnickers come to pick up the fish for they are fine pan fish with a delicate flavor. Some use seines, others screens, and a few dipnets. At the full of the moon—moonlight usually provides ample illumination for detecting the writhing, silvery creatures—or at new moon, when the fish also run, the grunion-gatherers assemble. Often they may have to rely on bonfires and flashlights.

The run, each night that it occurs, lasts only about an hour. It is not instinct like the grunions' that brings the crowds to the spot at precisely the right time, but a timetable prepared by Dr. Frances N. Clark and the staff of the California State Fisheries Laboratory. Obviously Dr. Clark and her co-workers do not have conferences with grunions to find out their plans for visiting the beaches, so until you know the clue, it is, to put it mildly, startling to find that you can make a definite engagement with a fish. Actually, thanks to observations and records made in 1918 by Dr. Will F. Thompson, formerly, Director, School of Fisheries of the University of Washington, Seattle, and to several similar studies made since, all that is needed to predict grunions' appearance ashore is the height and time of each nightly high tide occurring the first, second, third and fourth nights after the highest tide of the series at the full of the moon and new moon. At such times only, but at such times always, during the breeding season, do grunions go on the beaches to spawn.

Since the run starts about fifteen minutes after the crest of high tide, if high tide is at 9:30 P.M., for example, the first mass of grunions may be expected at 9:45 P.M., shortly after the high tide begins to recede and the moon is well above the horizon. Long before the tide is halfway out the run slackens; by the end of an hour it stops altogether, the fish disappearing into the sea in unison as if they had been signaled.

The underlying purpose of the grunions' excursion from their native element to deposit their eggs far up in the sand, only a foot or so below the highest point ever reached by a wave that breaks in the surf, seems more awesomely dramatic than the mass spectacle of the run. So strong is the instinct for survival of the species that these fishes venture nearly out of the water to place their eggs safe from aquatic enemies and under conditions favorable for their development and ultimate escape of the young into the sea.

After they have swum up in the swirling water almost as far as it goes, with their backs actually out of it, the males lie quiet for a moment on the sand, while the females—a little longer by about an inch—bury themselves tail downward. Then the females, almost vertical, stir the sand with their tails and fins, making it soft and fluid. When a female is buried in the sand up to her pectoral fins one or more males arch themselves around her, and she twists and bends from side to side (Figure 58). Then, as if she were tired, she frees herself from her semi-interment, and lies upon the sand.

Meanwhile the eggs have been laid and fertilized, and although it may sound as if all this has been a prolonged performance, in reality it is so brief that I venture to guess great numbers of the people who throng to gather wriggling grunions do not even know the significance of their appearance on the beach and their movements. From twenty to thirty seconds is about all the time a grunion spends in the place where it mates and deposits the eggs—the time between two waves, on one of which it has come up and into the other of which it flops to return to the sea. An occasional fish after it has fulfilled its purpose may miss a wave and, flapping about, may have to wait to catch the next one. On the other hand, at times a grunion will spawn so speedily that it makes a round trip with the same wave.

After the last run of grunion has disappeared in the sea nothing on the surface of the sand remains to indicate their short stay on land; but immediate digging will reveal eggs in groups of about two thousand lying two inches below. Soon, however, the eggs get a thicker sandy coverlet. After waves have broken their speed picks up loosened sand and transports it along with the sheet of water that washes up the sloping beach. When the water's momentum begins to slacken, when it stops altogether for a moment, it drops the sand. Dr. Thompson, searching for eggs the day after spawning, found none at the same depth he had found them the night before; further buried by sand that had been carried up by the waves, all were three to six inches down.

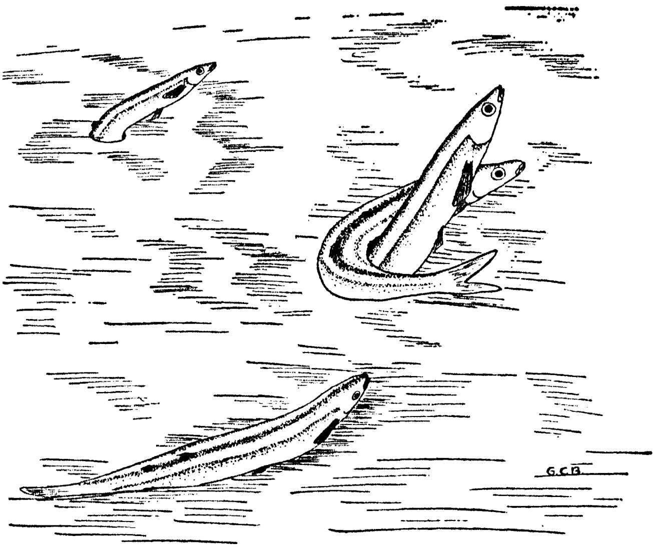

FIG. 58. Grunion, laying their eggs in the sandy beaches of Southern California, come out of the ocean to spawn. Nearly two weeks later the young are released from the sand by the waves at high tide. (After Clark.)

During the first few days following high tides the sand remains moist and firm, but by the tenth or eleventh day its surface is completely dried out. The eggs, undoubtedly adapted over the millions of years that this species has occurred along the warm California coast, are sufficiently moist to remain healthy. Furthermore, temperatures taken under the sand have shown that although its surface may be so hot that bare-footed bathers must step lively, below a two-inch depth it is only slightly warmed.

Two weeks after the eggs have been deposited comes the next series of high tides. The first of these has no effect upon the eggs because the excavating part of the waves is below them. But the next night the waves of a still higher tide sweep up the beach and dig out the eggs which forthwith hatch. Then that same wave which has liberated the young carries them back into the sea.

The babies grow rapidly during their first summer, more slowly during the winter, until by spring they are about five inches long and ready for their first spawning in early summer. From microscopic examination of their scales we know that they may live to three years and occasionally four, with growth ceasing during the spring and summer months, their spawning period.

How precisely adapted is the development of grunion eggs has been proved by laboratory studies. Some eggs were dug out the very night they were laid and kept in moist sand in glass jars so that it could be learned how and when the young escaped. After ten to twelve days salt water was placed in some of the jars, which were vigorously shaken to simulate the action of the surf. Almost immediately all the eggs hatched, the young coming out like popping corn and swimming about vigorously. But exactly nothing happened in the jars that were not shaken.

Other new-laid eggs were kept buried in sand for thirty days before water was introduced; again, those shaken hatched, but those in unagitated water remained eggs. Consequently we know that should eggs, ordinarily incubating in twelve days, for some reason miss being excavated by the first series of high tides occurring after they have been deposited, they will stay healthy for two weeks longer, until the next series of high tides can release them.

In still another experiment some eggs were dug out at night just before the highest tide that would normally cause them to hatch was reached, for the purpose of discovering whether the young would escape without the action of waves. But mature though these eggs were, they failed to hatch.

When I consider all the "ifs" conditioning the safe hatching of grunion eggs, I become even more impressed with the way the very existence of the species is tied up with the tides and the waves. For instance, if they were deposited lower down the beach instead of far above the average high tide, they would be freed long before they are ready for hatching, and the water would carry them back to the sea to their doom. If they were deposited fifteen minutes earlier, at the crest of the highest tide, and consequently above the reach of the average high tide, there would be no chance for them to be liberated. If they were laid where the sand were not soft and easily penetrated, they would remain on the surface to be the prey of birds, or to be baked in the famous southern California sunshine.

I do not know what mechanism acquaints the grunion with the tides with which its spawning habits so perfectly dovetail, any more than I know how the eels find their way to their spawning ground in the ocean. But the facts of such adaptations for survival, the fascination of their detail and the grandeur of their mass drama, and their ages-long, rhythmical repetition, make ichthyology such a continuously stirring and wondrous field of exploration.

Fishes That Spawn in the Surf

I shall never forget, for instance, the interest and excitement of a trip my wife and I took during early August, 1932, to see the spawning of silver smelts, one of the kinds of smelts that spawns in the surf. We drove from Seattle to a small town named Kaloloch, on the western shore of the Olympic peninsula. At about 6:30 P.M., equipped with dipnet, field glasses, notebook and measuring tape, we made our way among tall, majestic firs and cedars, some of them ten feet in diameter, to the ocean beach.

The waves were about three feet high, the breakers moderate. Having both grown up inland, we stood fascinated, listening to the waves that rolled in with a steady, monotonous roar and watching their crests curl over at the top as they approached, churn into a white foam and crash over and onto the beach, first with great speed, then with gradual slackening until finally the lip of the wash would spend itself about twenty yards up the sloping beach.

But breaking waves were not all we had come to see, with the complications and expense of making arrangements to park our then small son during our absence! We had come to see smelts, which I had heard had spawned in the vicinity a few days before. We knew that they were caught in this particular beach by fishermen who used scoop-nets in the breaking surf, thrusting them into waves beneath the onrushing crests. Yet not a smelt obliged us with its appearance. Had we disturbed the fish, we wondered?

Quietly and disconsolately we walked down into the water, cold around our boots. Suddenly, after about half an hour, we noted a little fluttering in the water, and a couple of glistening smelt were left stranded for a moment, until they disappeared in the next wave the moment the lapping water touched them. New waves brought many more of the five-to-eight-inch fish into view, but it took some time for us to see just what was happening. In fact, we observed the smelt for two days; later a group from the International Fisheries Commission, Seattle, studied them too, and we all wrote up our observations.

Once the smelt really began to run up the beach, on an area about three hundred feet long, they came in numbers beyond my wildest expectations; uncountable thousands. Paying not the slightest attention to my wife and me as we stood motionless in the cold water, they swam between our feet and struck our boots in their haste to get back in the sea on a receding wave. As a wave would break and a sheet of water, bubbled with air and sand-laden, would spread a few yards up the beach, we could indistinctly see groups of two to five swimming in it. Some swam parallel to the shore line, many others at various angles to it, but most straight up the sloping beach.

The fish were most active during the early part of the wave. As the water thinned out, the groups would break up as soon as they began to get uncovered and would rush back into the foaming surf. Occasionally some would venture too far up the beach and become stranded. Such unfortunates, if they escaped the greedy sea gulls which had gathered for a feast with unerring knowledge of the smelts' habits, would hastily swim back on the next wave.

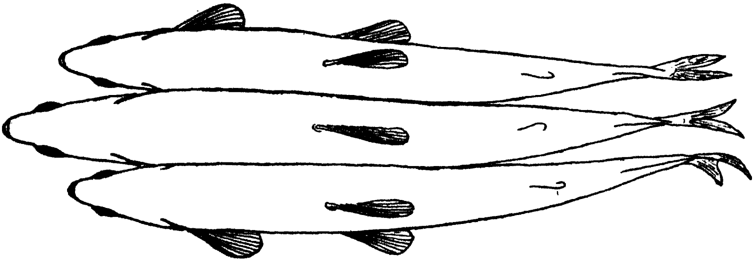

FIG. 59. A trio of spawning silver smelt as they appeared swimming up the beach with a wave.

A group would begin to form with the breaking of a wave. Coming out of the foam, one to three males—their undersides yellowish, their backs a dusky brownish tinge—would surround a large female, her back a steel blue-green, her underside white. Usually with one male at each side of a female (Figure 59), and others trying to crowd in too, the group would move as a unit, like an arm-locked trio of skaters, swimming up the beach with the onrushing water and vibrating rapidly for a few seconds. The water was too much disturbed and loaded with sand and gravel for us to see the eggs being deposited, but it was obvious that the silver smelt does not attempt to venture as far up a beach as grunions do, nor does it bury its eggs.

Undoubtedly with the males' pressure on the females' sides probably aiding extrusion, the eggs are laid during the vibratory movement on the upward swim, for when we placed fine-meshed nets in the water to catch the receding rush of the backwash we collected large numbers of white eggs about the size of pinheads. Their outer membrane is viscous; they stuck firmly and instantly to the net, or to the gravel caught in it, while the sand was still floating. When we caught females, held them over containers and pressed their sides, eggs flowed out and adhered to the bottoms and sides of the vessels immediately.

This adhesive quality, characteristic also of the eggs of all stream-spawning fishes such as salmon and trout, is Nature's method of adapting the reproductive habits of the silver smelt to the conditions under which it spawns.

As in the case of hibernating fishes, there is a life-saving correlation between the physical and the biological, the action of water and the habits of fishes. As each breaking wave floods the beach and dissolves in a mass of churning foam, it picks up gravel and sand; then, as its momentum is spent, it drops the largest and heaviest parts of its load first, carrying the lightest, or grains of sand, up the beach. Thus, on beaches of exactly the correct slope, halfway between high and low tide, sand and gravel are separated, with the gravel furthest down about the size of peas or peanuts. On the receding tide the fine sand is deposited in a thin layer over the surface of the gravel.

All of this adds up to safety for the eggs of the silver smelt, which habitually places them in the gravel region and during the wave's incoming. The bits of stone to which they fasten themselves serve as anchors during all the succeeding waves for a period of ten days to two weeks Had the gravel been covered with fine sand when they were laid, they would have adhered to that instead, and with the next wave have been carried farther up the beach; then, as the tide receded they would have been left literally high and dry—a condition to which they are not adapted. Instead, the layer of fine sand that settles over them with each receding tide, acts as protection against enemies, insulates them and keeps them moist. Nor are they unduly exposed when the next high tide occurs and the incoming waves remove the protecting sand, for then they are covered by water.

We wondered why these eggs were not wrecked by the continual pounding to which they were subjected by the surf, until we tested them by trampling on them, where they occurred by the millions on coarse gravel, and found that we did them no harm. Their hard, firm outer covering adapts them to tough treatment and quite the contrary from their suffering from the surf's apparent punishment, they benefit by it, for they are continually aerated.

As far as I know no one has ever worked out in much detail the spawning habits of the capelin, another kind of smelt, found in northern waters of the Pacific Ocean from British Columbia northward to Siberian shores, and in the Atlantic from Maine to Norway, nor of still another, the night surf smelt (Figure 60), found in the Pacific Northwest; but it is known that the latter spawns in the surf and only at night.

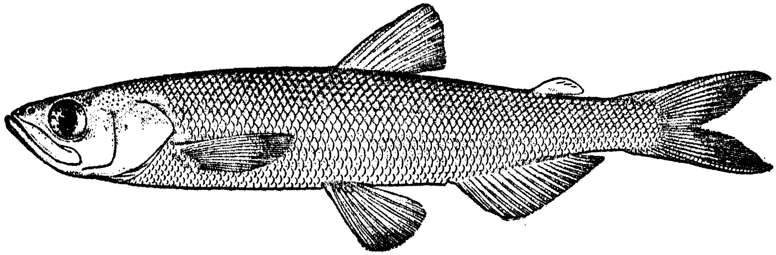

FIG. 60. The night surf smelt of the Pacific Northwest is known to spawn in sandy beaches of Washington. Details of its habits are unknown.

The spawning habits of the capelin are generally similar to those of the silver smelt, although there are vastly greater numbers of the capelin appearing at breeding time, when they occupy huge stretches of the sea coast. G. F. Sleggs of

Newfoundland, counting the number of capelin eggs in a cubic foot of gravel, found six or seven million. Since usually the top six inches—and sometimes twelve inches—almost up to the high tidal mark, are full of eggs, in a typical stretch of gravel one hundred yards long some ten billion eggs are attached. Many more millions are also attached to rocks and shells below the low tidal level. Catching some of the females, Sleggs found that the average one contained about 30,000 eggs; therefore it must take one third of a million females and at least as many males to cover a one hundred yard beach, in addition to at least another million which spawn below the tidal zone. Since capelin spawn along many miles of beaches of the North Atlantic, the combined smelt population of the two oceans must be enormous, almost beyond comprehension.

Such things must remain uncounted; but we do have quite a bit of statistical information on fishes' size.

12

GIANTS AND DWARFS

FISHES have a greater range in size than any other group of vertebrates. The length of a mouse compared to the length of an elephant does not present as sharp a contrast as the length of some of the tiny gobies compared to the length of a whale shark. Even the largest mammal, the whale, is only 527 times longer than the smallest mammal, the 65-mm.-long shrew, whereas the longest whale shark is over 2000 times longer than the shortest fish.

The Growth of Fishes

Unlike us humans, who stop growing at a certain point in our development, fishes grow throughout their lives, although, like trees, their rate of growth slackens as they age.

As the age of a tree can be told by counting the rings on a cross section of its trunk, so can the age of temperate zone fishes be gauged by microscopic examination and a count of markings on their scales. Since scales grow in the same proportion as a fish's body in general, during the cold season when growth is so slow it almost ceases, circular lines or marks form close together; during warmer periods, when there is more rapid growth, the space between the lines or marks is wider. Each cluster of similarly spaced markings is called a "ring," and a "winter ring" and a "summer ring" denote a year of a fish's life.

Many laymen, even experienced fishermen, have the notion that a fish bigger than the average of its kind must be an old one. This is a fallacy. Since other factors besides age influence growth the particular specimen may simply be large for its age—as most mothers fondly believe their own offspring to be.

Temperature and food supply influence rate of growth. If fish ordinarily found in water that is merely cool happen to live in water so cold that food is meagre and metabolic processes are almost continuously slowed down, they are likely to be stunted. During my survey of fishes in Glacier National Park in 1934, I found, in the frigid waters of a mountain stream ice-free four months, at most, during the year, seven- or eight-year-old cut-throat trout only six inches long. Compared to other members of their species who attain lengths of a foot and a half, these were indeed runts.

The growth-retarding effect of cold water, however, applies only when temperature is down at an extreme. Pacific sardines, or pilchards, and Pacific herring, which have a long range—from Mexico and southern California to British Columbia and Alaska—live in waters that run from coolish to cold, but not icy. Northern members of the species have a slower rate of growth than the southern, and attain sexual maturity later; but they live longer. Their longevity, together with the fact that in all fishes the rate of growth is most rapid before sexual maturity, causes them to become on the average as much as twice as long as those of their kind who reach maturity sooner and die younger.

The Larger Fish

Frequently I get letters asking: "What is the largest fish and the smallest fish?"

We Americans love superlatives, and scientists are no more immune than anyone else from the satisfaction of establishing them. Ichthyologists as well as sportsmen are perennially looking for "the biggest fish." Dr. Gudger, indeed, made the search for it an avocation within his vocation. Not only was he after the biggest fish in the world, and the biggest specimen of the biggest fish, but also the biggest fish in India, and in South America, and in Europe, and the biggest fresh-water fish, and so on, sub-category under category!

The big fishes have one almost incredible feature in common: all originate from tiny eggs no larger than the head of a pin. In behavior and temperament, however, they share no similarity. Some, such as the giant groupers or black cod (reaching a weight of 600 pounds), the barracuda (an eight-footer, caught in the Australian region, tipping the scales at 120 pounds) and the giant stingray (750 pounds, fourteen feet or more) are dangerous to man. Others are neither predatory nor venomous.

The Largest Marine Fishes

There is, for instance, that peace-loving giant among marine fishes, the ocean sunfish, or head fish, *Mola* (Figure 61),

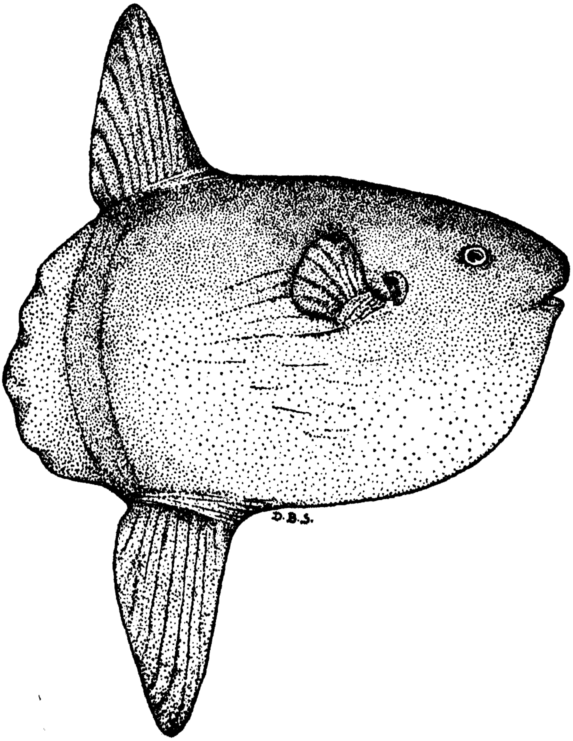

FIG. 61. The headfish, *Mola*, is also known as the ocean sunfish. It lives in the warm seas of the world where it is often seen at the surface "sunning" itself.

which spends a considerable part of the time floating on the surface and sunning itself, hence one of its common names. The other originates from its shape, for it is wider than it is long. Despite the head fish's seemingly unsubstantial diet of jelly fishes, it certainly puts on weight. An Atlantic coast specimen measured ten feet in length, twelve from the tip of its dorsal fin to the tip of its anal, and had an estimated weight of 1200 pounds. But even this creature was small compared to an Australian specimen reported by David G. Stead.

The Australian fish was not taken by design but by accident. On September 18, 1908, a little after 1:00 P.M., the *S.S. Fiona,* off the coast of New South Wales about forty miles from Sydney, suddenly shook from stem to stern and her port engine stopped dead. A boat was lowered, and captain and crew saw, jammed into the port propeller, an organic mass resembling an elephant in both bulk and skin texture. What they called it Stead does not report, but likely it was something besides "a fish." At any rate, it was impossible to dislodge the creature, so the *Fiona* limped into port with only one propeller, and her impediment perforce went along. While a crowd stood by gazing and gaping, a huge iron hook, especially forged for the purpose, was lowered into the water and used to dislodge the enmeshed fish. Here sailors' poison was ichthyologists' meat, for had it been possible to remove the fish at sea, the largest ocean sunfish on record would never have been weighed and measured. It was two and a half feet thick, ten feet two inches long, thirteen feet four inches from the tip of its dorsal fin to the tip of its anal, and, perhaps most startling, weighed 4400 pounds—over two tons!

A still bigger and heavier marine fish, the Arctic or basking shark, often measures twenty or thirty feet long (Figure 62). The longest basking shark recorded measured forty feet and its estimated weight was 30,000 pounds. But the colossus of all waters, fresh and salt, is the whale shark, occurring in all warm seas, with round pale areas about the size of silver

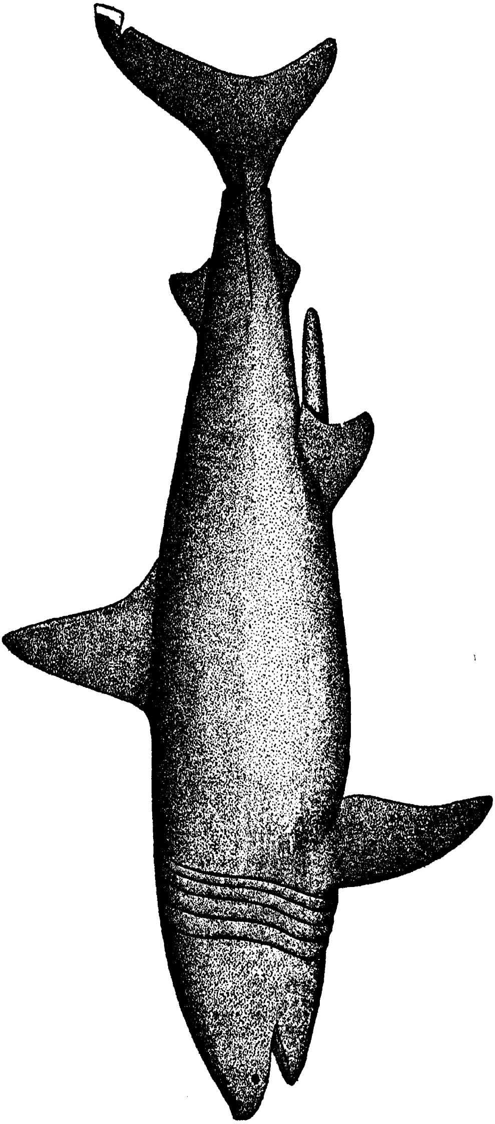

FIG. 62. The basking shark, *Cetorhinus*, is the largest fish of the northern seas.

dollars spotting its dark body (Figure 63). Most whale sharks run about eighteen to twenty-five feet; captured specimens have measured thirty-four, thirty-eight and forty-five respectively, and specimens seen in the water have been estimated by experienced persons to be as long as seventy feet and to weigh 150,000 pounds.

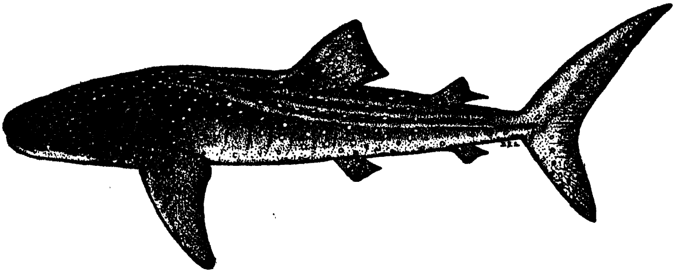

Fig. 63. The largest fish of all is the whale shark, *Rhincodon*. Its length has been measured at 45 feet and larger ones have been estimated at 70 feet. (Modified after Gudger.)

The Largest Fresh-water Fishes

Nevertheless, although they cannot claim world title as "the largest," a number of fresh-water fishes are not exactly pygmies. One of these massive fresh-water fishes is the goonch, a catfish of India. The largest specimen recorded, taken from the Jumua River near Okhla, was about five and a half feet long, but Dr. Hora says this fish may grow to a length of six feet and a weight of 250 pounds. Because of its underslung jaw, gray color and predatory habits, the goonch has been called "fresh-water shark" and, according to Dr. Hora, altogether it is a formidable creature.

A European catfish, *Siluris glanis* (giant catfish), justifies its name. Native to the Danube and other large rivers of eastern and northern Europe, it grows to lengths of nine or ten feet. Like other catfishes, its mouth, set in a head wider than its body, is over-sized out of all usual proportion, and although it feeds normally on other fishes, frogs, crustaceans and worms, it is reported to eat anything it can swallow. In

1858, near Vienna, a poodle dog was found in a giant catfish's stomach. Various writers tell of this fish's consumption of other small mammals, ducks and geese, while some ancient accounts go as far as to mention the swallowing of children. Through the ages there have been persistent tales of swimmers being swallowed by the *glanis,* but Dr. Gudger, who has compiled such stories, is inclined to take them with a grain of salt. Even the largest *glanis,* he says, could not possibly have room in its stomach for a full-grown boy, and he thinks the stories arose from discoveries in the monstrous catfishs' stomachs of parts of corpses of the drowned.

Another big catfish, over six and a half feet long, pla buk (*pla,* fish; *buk,* huge), or trey reach (royal fish), occurs in Siam. Without teeth in its jaws and feeding entirely on vegetation, in the course of cropping algae off stones, it sometimes swallows indigestible mineral as well as digestible vegetable matter. Rocks the size of a man's fist have been found in pla buks' stomachs.

This fish has never been taken in the sea. However, during the August-September floodwater period, it occurs in the

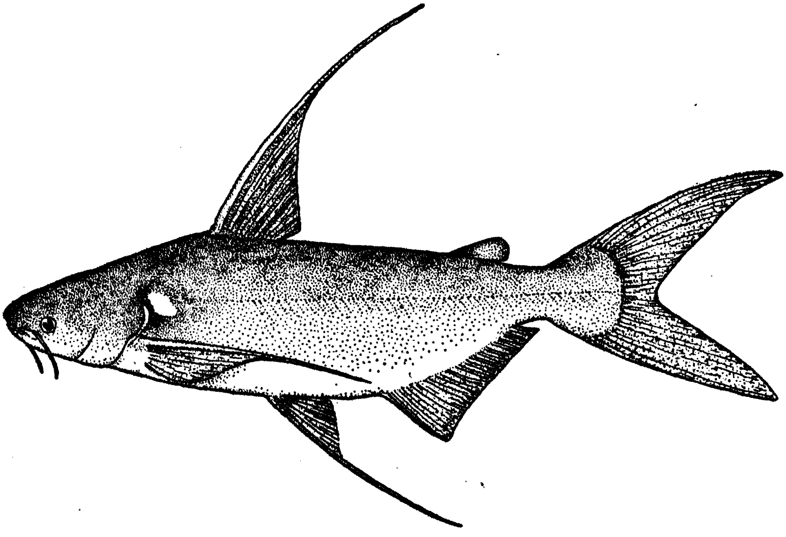

FIG. 64. ***Pangasius,*** **the Royal fish, is the largest catfish in the world. (After H. M. Smith.)**

lower Mekong in the region of Cambodia; then, when the rainy season has ended and the flood waters begin to subside, it starts an upstream migration apparently for the purpose of spawning. In February it reaches the region of Laos, where it is intensively fished; later it traverses the entire length of Siam and crosses the border into southern China.

Although it is called the royal fish, the pla buk is exceeded in length by another Siamese catfish, *Pangasius,* a ten-footer, which is the largest known catfish in the world (Figure 64).

Siam is the locale also of a mammoth representative of another fish family, the minnows. To anyone accustomed to thinking of "minnows" as little fishes it doubtless comes under the head of news that a minnow is capable of towing a boat. Questing for "the largest fresh-water fish in Siam"—or, with luck, the world—Dr. Smith found in the Menam River a kind of giant minnow eight feet two inches long and 300 pounds in weight. This fish is caught with a hand line, and a fisherman who has hooked one sits tight and lets his boat be pulled about until the fish is tired out, a matter of two or three hours. Another enormous member of the minnow family is the mahseer, one of the largest fresh-water fishes of India. A sport and game fish, it reaches a length of five and a half feet and a weight of 150 pounds.

In North America, the largest member of the minnow family is the nearly three-foot long squawfish of the Colorado, Columbia and Fraser River systems. But we need not go as far away as Asia to find spectacularly big fishes. White sturgeon occurring in the Columbia and Fraser River systems attain impressive dimensions. The biggest white sturgeon of all was recorded by A. B. Chapman, father of Dr. W. M. Chapman, Curator of Fishes, California Academy of Sciences. It was taken in May or early June, 1912, was twelve and a half feet long, and weighed 1285 pounds, including 125 pounds of roe. While I was at the University of Washington, L. J. Farley of Prosser, Washington, in the summer of 1933 at the mouth of the Yakima River, a tributary of the Columbia, caught a sizeable specimen weighing 826 pounds and measuring eleven and a half feet. It achieved the distinction of having its picture in the paper.

Sturgeon, now a scarce and an expensive delicacy, were once abundant in North America. But because there was no market for them they used to be destroyed as nuisances when they appeared in fishermen's nets, and were piled up along the river banks as waste. Chinese and Manchurians, often hard-pressed for food, are not so thriftless, and expertly fish the four great sturgeons occurring in the rivers of their countries.

The largest sturgeons of all, which are also the largest fresh-water fishes in the world, have been found in Russia (Figure 65). Dr. L. S. Berg, Russian ichthyologist, reports one weighing a ton and thirteen feet long. Ferdinand Hansen, president of the Romanoff Caviar Company, wrote to me several years ago that he saw a 2250-pound, fourteen-foot-two-inch-long sturgeon which had been caught in the Volga River near Astrakhan. All the larger reported specimens of sturgeon are females. Their roe, especially when expertly prepared in Russia, is that gourmet's delight, caviar.

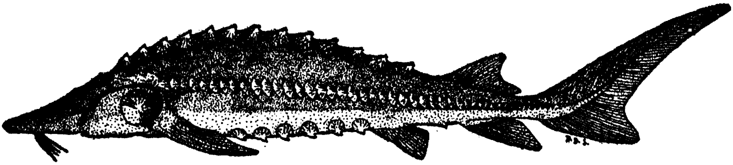

FIG. 65. *Huso,* a sturgeon of the Amur River of Northern Asia, is the largest known fresh-water fish of the world.

Related to the sturgeon are the curiously shaped paddle fish, of which there are only two known kinds (Figure 66), one in the Mississippi River and the other in China. The Chinese fish is the longer, and is said to reach a length of twenty-two feet, although the largest one actually measured and reported by Dr. Gudger was twelve feet. The projecting, paddle-like snouts which give these fishes their name are about one-third the length of their bodies, and both in the mud-laden Yellow River and the Mississippi, are used as an aid in locating food at the bottom. Laymen's reports that the paddles are also used for stirring up the bottom are erroneous: these organs are too sensitive to be used comfortably as bull-dozers. Paddle fish are so slender in proportion to their length that their weight does not bring them anywhere near the title of "biggest fresh-water fish" held by their relatives; but should one of my colleagues, in the search for superlatives, start tracking down the "fish with the longest snout," this one among fishes would certainly be a candidate.

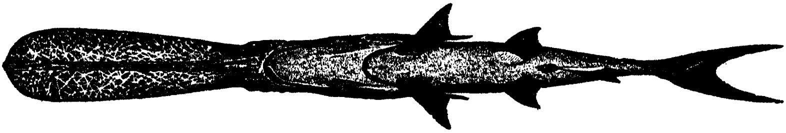

FIG. 66. The paddle fish, *Polyodon,* of the Mississippi basin of North America.

How the Weight of Fishes May Be Estimated

It is no simple matter to weigh a fish longer than a man and whose weight runs into three or four figures. Usually the weight of a very large fish has to be estimated. The method, although more likely to be used by practical necessity in the case of tremendous fishes, is applicable to any fish of streamlined shape, but not very accurate for odd-shaped fishes such as the tresher shark (Figure 67). To calculate the weight of a fish, all you need to know is its length from the tip of the snout to the base of the tail fin. The formula is: weight increases to the 2.8 power of the length times a factor.

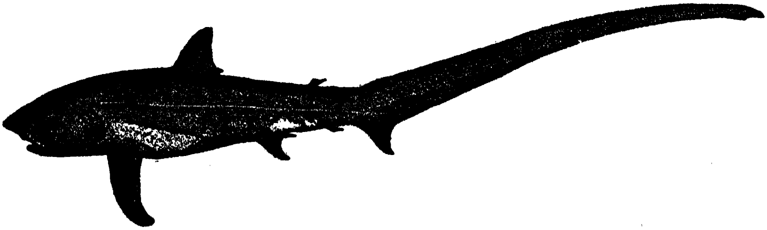

FIG. 67. The thresher shark has the longest tail of all sharks.

For example: a shark measuring 157 inches, or thirteen feet one inch, from the tip of the snout to the notch at the base of the lower lobe of the caudal fin, would weigh 1190 pounds. A whale shark twenty-six feet two inches would weigh 5500 pounds.

It was a fossil shark's tooth that stimulated me to work out this method of estimating weight for big fish. One day a man brought to my office the largest fossil shark's tooth I had ever seen: it was four and a quarter by five inches. He had picked it up on the shore of Chesapeake Bay just north of Scientists' Cliffs, where my children and I have found thousand of fossil sharks' teeth of various kinds. He asked me to what kind of shark this tooth had belonged. The answer to that was easy: I told him, "the great white shark, or man-eater shark." But I also informed him that he had indeed made a find, for no one has ever caught a living shark with teeth over three inches across.

He then inquired whether there was any way of estimating the weight of a fish by its teeth, and if so, how big was the shark to which this gigantic tooth had belonged? I explained that as teeth and scales usually grow in proportion to the rest of a fish, as soon as I knew exactly the length of a shark with a two and a half inch tooth, and the length and tooth measurement of some smaller sharks, I could probably give him a pretty good estimate. I would figure, I said, according to a rather rough guess made by Theodore Gill at the end of the last century. By this method the weight of a fish was estimated as increasing as the cube of the length; it was in general use.

However, estimates had been worked out only on fishes up to a yard in length; nobody had ever applied the method to big fishes. I became fascinated by that big tooth and the unknown weight of its extinct owner, so I determined to refine the method and get the greatest possible accuracy.

I proceeded to obtain authoritatively known weights and lengths of thirteen adult whales, forty-three baby whales, thirty-four sharks and twenty-three marlins, casting out at

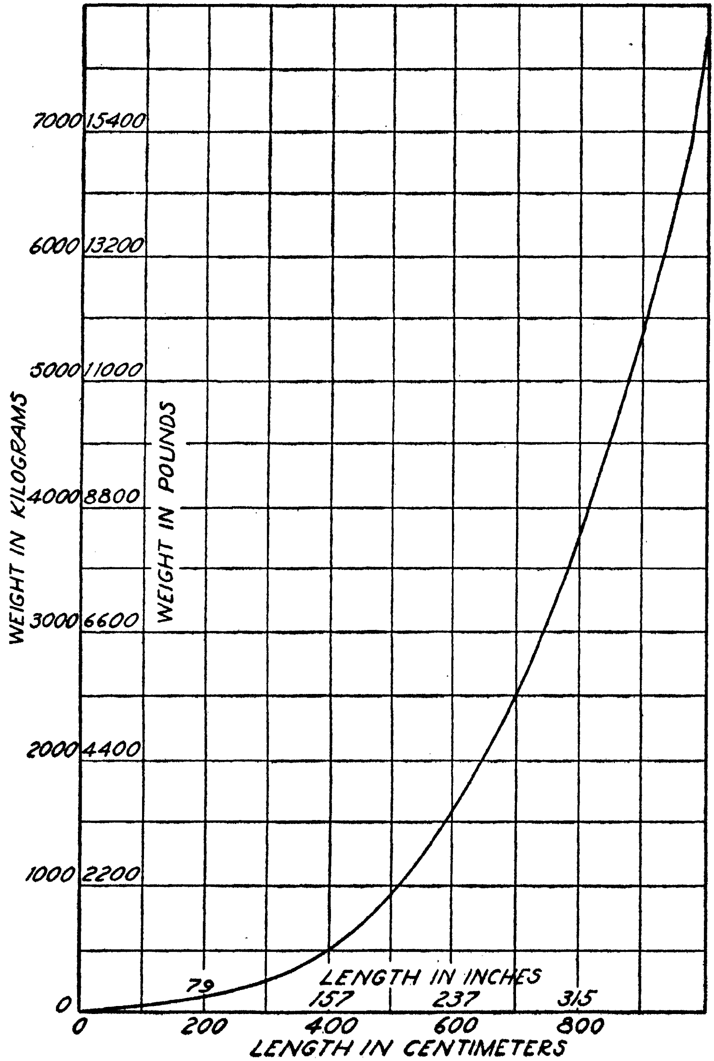

FIG. 68. By means of this chart the weights of moderate sized fishes may be estimated. Length is measured from snout tip to base of tail fin. (After Schultz.)

least as many more I could not be absolutely sure were authentic. Thus I was able to work out the ratio showing that instead of increasing at the cube, actually the weight of these fish and the whales increased at 2.8 power of their length (Figures 68 and 69).

At the Smithsonian we have the jaws of a great white shark. The teeth are two inches across, and the specimen from

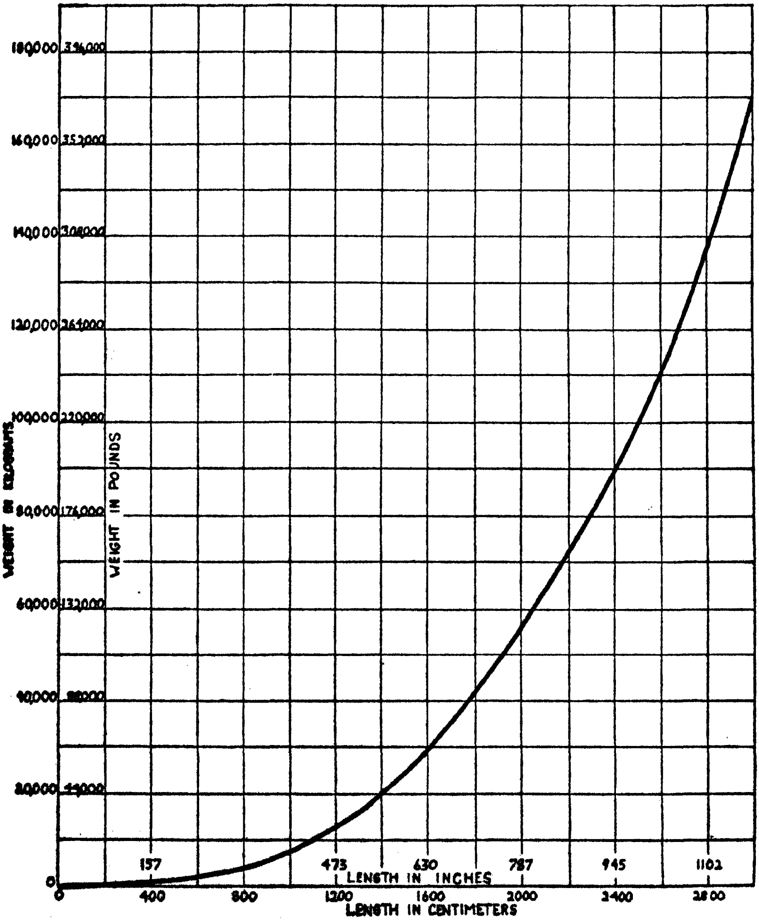

FIG. 69. With this chart you may estimate the weights of large fish and whales. (After Schultz.)

which the jaws were taken measured thirty feet in length. Another shark in the British Museum has teeth three inches across and was forty feet long. Hence, since teeth grow at the same rate as the body, the tooth measuring five inches across would have come from a great white shark that was sixty feet long and weighed 100,000 pounds.

The Smaller Fishes

To ascertain "the smallest fish in the world" requires neither such mathematical calculating nor scales of any kind. A large number of specimens of a potential "smallest" are assembled in order to get their range in length, measured in millimeters. So diminutive are some of the tinier fishes that they are no larger than the larvae (just hatched) and post-larvae (before metamorphis into fish) stages of most fishes and to measure them in terms of inches would be almost as gross as to attempt to weigh a baby in terms of tons. The longest adults and sexually mature specimens among the lot, if they turn out to be shorter than any other known fish, then bring to their species the distinction of being "the smallest."

Simple enough: but over a period there have been several "smallest" fishes, each having to relinquish the honor when a still smaller fish was discovered!

In 1858 Dr. C. F. Girard of the Smithsonian Institution reported as "the smallest fish" the mosquito-larvae-eating *Heterandria formosa,* one of the toothed carp found along weedy edges from South Carolina to Florida. The longest full-grown female measured twenty-eight and a half millimeters (one inch); the longest male twenty-one millimeters (three-quarters of an inch).

Heterandria formosa was displaced in 1895, when Dr. Samuel F. Garman, Harvard College, announced that another species, *Heterandria minor,* measured even less—seventeen and a half to twenty millimeters.

The United States' conquest of the Philippines and new chemical methods of collecting, which could bring infinitesimal fishes out of almost equally infinitesimal crevices, in turn ousted *Heterandria minor.* In January, 1902, Dr. Smith published a note on "the smallest vertebrate known," a fish he had received from Lake Buhi in the Philippines. It was one of the gobies, and he named it *Mistichthys luzonensis,* a name much longer than the fish itself. This fish is transparent when it is alive, has large black eyes, and a few faint blackish bars on its body. The female deposits twenty to forty eggs about .37 of a millimeter in diameter, and each egg is provided with a tuft of filaments for attachment to objects. *Mistichthys luzonensis* measures ten to fourteen millimeters and, almost unbelievably, is used by the Filipinos as food. The fish which congregate in schools are scooped up in fine-meshed nets or cloths, the water is drained off and they are sold in bulk—16,000 of them to the pound—to be dried into cakes.

Dr. Smith's discovery of a new "smallest fish" challenged and stimulated other ichthyologists, among them Einar Lonnberg of Sweden and Arthur W. Henn of the Carnegie Museum, Pittsburgh, to hunt afresh for still another bantam champion. But for almost three decades *Mistichthys luzonensis* held its title.

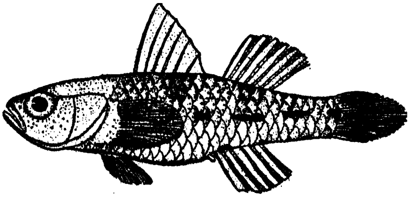

FIG. 70. The smallest known vertebrate is the little goby, *Pandaka pygmea,* from the Philippines. (After Herre.)

As a family, the gobies still remain the smallest known vertebrates. Structurally complete miniatures of larger gobies, several kinds run no longer than fifteen to forty millimeters. But as the smallest species of the family of smallest fishes, *Mistichthys luzonensis* is passée: a slightly smaller relative, seven and a half to eleven and a half millimeters when adult, has been established as the smallest fish in the world.

Its name, *Pandaka pygmea*, means dwarf pygmy; it comes from Malabon in the Philippines (Figure 70). Like all the gobies it is an egg-layer, and it owes its world recognition to Dr. Herre, who published a paper on it in 1929. To date no one has discovered a still smaller fish. I did my best to find one at Bikini, but no luck!

Another quest, this one to establish details of spawning habits, was more successful.

13

NEST BUILDERS IN STREAMS

SOME people are fascinated by watching horses race, others enjoy seeing chorus girls cavort, while still others delight in looking at monkeys' antics at the zoo. Personally, I get more pleasure from making close observations of the ways of fishes. Also, I must admit, there is satisfaction in thinking that by investigating habits never before noted or recorded, I might be adding my bit to the store of knowledge. Such was the case with my 1930-1933 observation and study of the breeding activities of a land-locked form of the red salmon, dwarfed in lakes to ten to twelve inches. When it migrates into streams, and the males' usual silvery coloration turns crimson to dark red, it is called little redfish; when it occurs in a lake, it is known as silver trout.

A Fish That Excavates by Flexion

This fish does nothing as spectacular as walking on dry land, or giving electrical shocks, or traveling en masse for three thousand miles like the eels. In fact, the details of its habits are relatively humdrum. But they add up to a story of indomitability, perseverance and fortitude almost never equaled by man except, perhaps, when he is under the stress of war. During the breeding season the little redfish, like other nest-builders in streams, spends itself in creating safe shelters for its eggs and in reproducing, in order that the species may survive. It was my privilege to see, from beginning to end, both the drudgery and the heroism of this patient, intrepid fish's spawning activities.

About September first, a few little redfish may be seen playing in the riffles of Swamp Creek, Washington, where I concentrated my study. After the first big fall rain, usually during September or early October, they appear in great numbers. In November they are at the peak of their abundance. Early in December the run begins sharply to decrease, and after the middle of the month the fish are all gone.

With me, on my autumnal habit-hunting trips for the purpose of instruction in methods of making field observations, were a dozen of my students from the University of Washington. One of these young men, Dr. Daniel Merriman, has since become director of the Bingham Oceanographic Laboratory at Yale University. Two others, Dr. Lauren R. Donaldson, professor of fisheries, and Dr. Arthur Welander, assistant professor of fisheries, are on the faculty of the University of Washington.

The small stream that was our favorite place for observation flows into the northern end of Lake Washington at Seattle. The adjoining land has been logged off; the margins of the creek are thickly overgrown with brush. The creek ranges in width from six to thirty-five feet, and in depth from six feet where there are quiet pools to a few inches where there are riffles or rapids. My students gave me invaluable assistance in mapping our selected section of Swamp Creek (Figure 71), down to every pool and riffle in its several series of them; in locating spawning spots—always on riffles shaded by overhanging branches—and in noting the fish's behavior.

We had to approach the riffles with great caution, for any sudden movement frightened the fish, and they sought shelter in deep pools above or below the riffles or alongside them, under overhanging banks. There they would stay for some time before venturing forth. We learned to remain quite still for from five to twenty minutes. A fish would swim quickly back, as if trying out the safety of the place, then away; but it would return. Shortly other fish would follow, always, however, making their own tryouts before they decided to remain on the riffle. An abrupt movement would again make them dart off, and we would have to wait for them to return, repeat their scouting routine, and once more become accustomed to our presence.

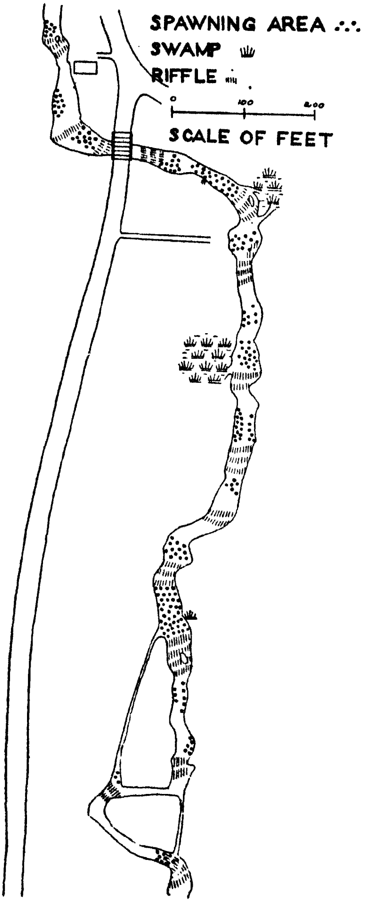

FIG. 71. The area in Swamp Creek where we studied the redfish was drawn by Milner B. Schaefer, now of the Fish and Wildlife Service. (After Schultz and Students.)

I learned to make slow movements, if any, while I was standing in a riffle. After a while I became merely a part of the landscape to the fish, and unworried they went about their business of making a home and starting a family; the females drudging like a housewife in her kitchen, the males combatting invaders like a pioneer father beating off Indians, and with the same general objective; to make home safe and to do for the coming generation.

Much as a wife and mother generally has the chief say-so in choosing a house or apartment, the female is the one who selects the place for the nest. Dull to dark-greenish-red, she is easily distinguishable from the brilliantly colored male, identifiable in addition by his slightly hooked snout and lower jaw. When she finds a spot in a riffle she considers suitable, she lets herself drift over its lower center, turns on her side, and four or five times in succession vigorously flexes her body against the bottom.

These movements have two effects. First, they carry her about a foot or a little more upstream. Second, the quick strong lifting of her tail raises bottom stones and sand. Before these have time to settle, the current drifts them downstream. The heaviest stones travel only two or three inches; most of the excavated material settles within a foot of its original location, while the finest particles are carried further downstream.

Meanwhile the female resumes normal position, returns to her starting point, and over and over again repeats her flexion and excavating. Thus gradually, and with unremitting energy and persistence, she builds a nest about eighteen by twenty-four inches, and two or three inches deep. Its floor, composed of stones half an inch to four inches in diameter, is clean of sediment; finer gravel and small stones are heaped in a low crescent-shaped mound on the downstream side. The shape of the nest depends to a large extent on the speed of the water's flow: the slower it is, the rounder the nest. Where it is swift, the nest becomes extremely elongate.

With a stopwatch I timed the females' nest-building activity. Each series of flexions took from two to four seconds. The intervals between them varied, but averaged one to every fifteen to forty seconds unless she was interrupted in her digging by an invader.

Perhaps one in a hundred males helped with nest-building. The rest do as little to lighten the females' labors as husbands who sit and play solitaire or read the newspaper while their wives are washing walls.

Gradually most of the fish break up into bisexual pairs, each couple, sometimes in water so shallow the edges of their backs are exposed, appropriating as its particular territory a nest and some of the surrounding area. Although both staunchly protect their home and grounds by rushing furi-

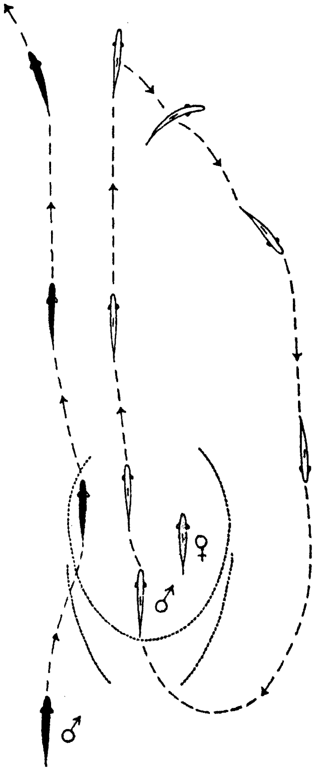

FIG. 72. A diagram illustrating the escorting act of the male redfish. Note that the female ♀ remains over the nest while the male ♂ drives the invader, solid black, away. The male and female are shown in their normal positions over the nest. (Drawn by Daniel Merriman; after Schultz and Students.)

ously at an invader, in justice to the male I must say he contributes the lion's share of the defense. Generally the female restricts her guarding to the upper section of the proprietary area, while the male, like the masculine partner in the usual mixed doubles, covers it all.

It was fascinating to observe the details of the nests' defense. Sometimes a male would catch his teeth in the lower side of an invader and the two would drift a short distance downstream before becoming separated; then the defender would return home immediately and take up his habitual position over the nest, a little behind and at one side of the female, his snout nearly opposite her tail. Sometimes when the invader approached from the side, the defender, raising his dorsal fin and exposing his red color, would rush out and swim towards him. When the fish were about a foot apart, the invader was frequently scared away. If not, the two would turn, and, parallel, swim slowly upstream for from two to five yards (Figure 72). The invader would thereupon peacefully call it a day and continue on his way, or would make another rush for the nest. If the latter, the escorting act would be repeated until either the interloper departed or the rightful owner of the nest was dispossessed. After a while we were able to recognize individual fish and follow their moves. One male drove off half a dozen invaders in an hour's time. One female stayed over the nest almost a week.

As a female is drifting back to the nest's center, between excavating acts, her partner approaches her, usually from behind and a little from one side, and with his snout gently touches her between her pectoral and adipose fins (Figure 73). He then moves forward a bit, stiffens, vigorously quivers for a second or two, and partially erects his dorsal fin. This act of courtship is repeated a number of times at intervals slightly less than a minute apart; but the female, apparently with her mind on her work of nest building, seems to be almost completely indifferent to it.

All the while the paired-off couples were devoting themselves to home-making, home-guarding and propagation, we

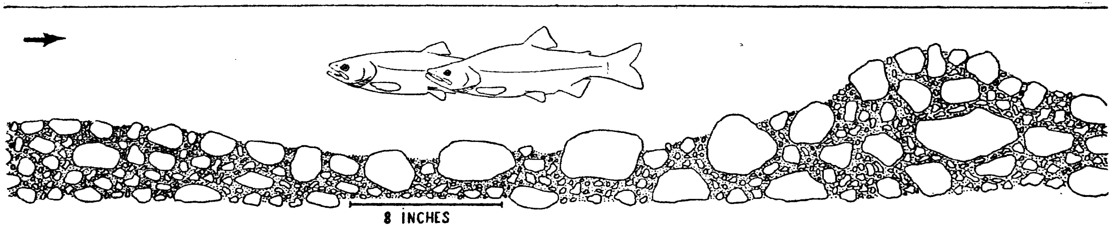

Fig. 73. A lateral view of a pair of redfish over a nest to show their relative positions during the act of courtship. (Drawn by Daniel Merriman; after Schultz and Students.)

noticed much splashing above and below the nest areas. We discovered this was caused by the carefree bachelors among the little redfish; unpaired males who darted hither and thither, leaped out of the water and fought among themselves.

Few people have ever witnessed the egg-laying act; indeed, before we made this study, the nest-building act was mistaken for the actual egg-laying in most descriptions of the breeding of salmon. Two of my students saw it definitely; I saw it once, I believe. The female, with her head upstream, settles down on the bottom in the center of the nest. The male quickly swims up beside her and slightly curves his body against hers (Figure 74). With both temporarily suspending all swimming actions, they tremble for two or three seconds while the eggs and the milt (the fertilizing fluid of the male) are extruded. The milt appears as a milky cloud that for a moment permeates the whole bottom of the nest; then it is carried away. The eggs settle down between the small stones of the nest's floor; eddies carry them against the stones and,

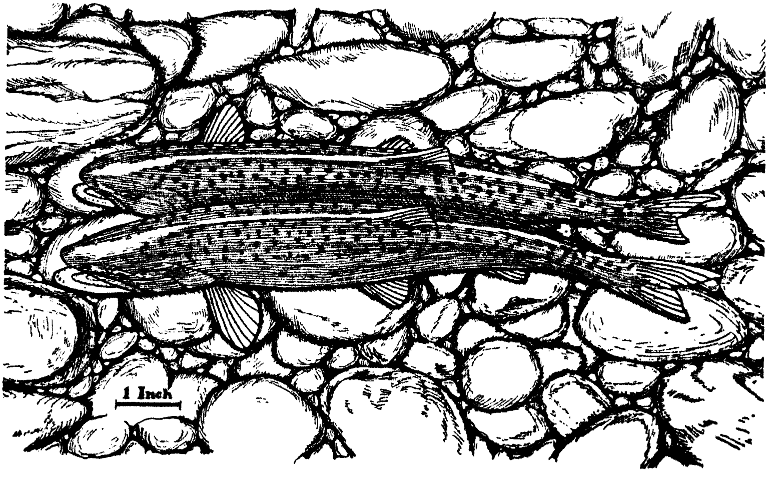

FIG. 74. A diagram of the egg laying act of the little redfish. (Drawn by Arthur Welander; after Schultz and Students.)

because when first laid they are sticky, there they hold fast, protected against drifting downstream.

As soon as she has deposited the eggs the female turns on her side and resumes flexing. Since she is not digging in the pit where the eggs are located, but slightly upstream, her operations kill two birds with one stone. The nest is extended, creating shelter for forthcoming eggs. The eggs already laid become covered, for the current sweeps the material she excavates over them, and within an hour or two they are usually snug under a one-to-two-inch thick gravelly blanket. As she works her way upstream the first-laid batches of eggs are covered deeper and deeper, sometimes to a depth of as much as four to six inches.

Time after time the spawning activities are repeated. Tail fins become worn from usage. Some of the fish bear wounds. None has eaten since it started its migration. The once lively little creatures become feeble, decrepit and exhausted, yet with a kind of instinctive heroism, they go on and on with their de-energizing nest-building, defenses, courtship and egg-laying. I have seen females attempt to dig when they lacked the strength to stay in the current. I have seen them still struggling to swim upstream as they drifted. Ultimately they had to give up and, like all Pacific salmon after spawning, die. Each year, before we left Swamp Creek for the season, the banks of the stream were lined with little corpses.

The Spawning of Salmon and Trout

Essentially, the breeding behavior of all salmon and trout is the same as that of the redfish. They seek a particular type of stream bottom, a gravelly or stony section in almost clear, rapidly flowing water, and if they cannot locate a bottom meeting these conditions they may die without ever having spawned.

There is practically no chance of salmon and trout eggs surviving out of the nest. Those washed out by sudden heavy rainstorms, those left high and dry in streams that have receded, perish. Another hazard to which the eggs are exposed is a fungus that spreads and consumes living eggs when a batch has been laid too close together and some die.

The marvelous adaptation of the eggs, physiologically and structurally, to the conditions under which they are laid and fertilized, is also common to all these fishes. From laboratory study of the eggs of the little redfish I learned that, if the eggs were not fertilized the moment they enter the water, they would not be fertilized at all, not only because the milt would be carried away by the current but because within five minutes after being deposited they become so swollen and water-hardened that the spermatozoa in the milt could not possibly enter them.

Despite all the similarities in the breeding behavior and adaptive qualities of the eggs of all salmon and trout, there are certain variations in their reproductive processes. For one thing, the time it takes for the eggs to hatch depends on the species and water temperature—the colder the water, the longer the incubation period—and ranges from two weeks to six months.

Also the time of year that migrations occur and eggs are laid is highly variable. Atlantic salmon, eastern brook trout, dolly varden, lake trout and brown trout, like the redfish, spawn in autumn. Cut-throat trout are typically spring spawners. The steelhead or rainbow trout—which, despite controversy about it, I am convinced is the same species—along the Pacific coast spawns in late autumn and winter, except in certain high mountain streams where it spawns in early spring.

A spring spawner, too, is another nest-builder in streams, in its own way as interesting in its breeding habits and life history as the salmon and trout, and one on whom I have, like the little redfish, made personal observations in the Pacific Northwest. It is a small species of non-parasitic lamprey.

A Fish That Excavates by Vibrating Its Body

During the first warm weather of spring, when the water in streams is about fifty to fifty-two degrees, adult western brook lampreys about the size and shape of a pencil begin to appear over gravelly riffles, and remain from April through early July. There, just where the water starts to go over the stones and flows fast, they make nests, usually three to six inches in diameter and two inches deep. They are not easily frightened away by movements or shadows in the water, but should the nest be disturbed they flee immediately.

Their excavating technique differs from that of the redfish. To loosen stones, both males and females wedge themselves between them, and vibrate rapidly. This motion also loosens sand and fine gravel, which is carried off a little distance downstream. Or sometimes the fish scoop out finer material by attaching themselves to a stone by means of their suctorial mouths and, without moving the stone, quiver to raise a cloud of sand. They frequently remove stones up to half an inch in diameter in their mouths, and carry them away downstream; thus on a small scale duplicating the nest-constructing activities of their larger relatives, the parasitic lampreys, who excavate with great vigor and carry more sizeable stones upstream as well as down.

When a pair of western brook lampreys have scooped out their nest, the female attaches herself by her mouth to a stone at the front part of the hollow, and the male similarly attaches himself to her middle. Then, after sliding along to just behind her gill openings, he curls himself around her and both tremble for two or three seconds, during which the eggs are laid and fertilized. The motions of the pair stir up sand in the nest bottom, some of which adheres to the eggs and loads them sufficiently to stay put. Egg-laying and fertilizing are then repeated until the female is rid of all her eggs. Like the salmon the lampreys move upstream during their spawning activities, but only a very small distance.

I took some lampreys from their spawning grounds and put them in an aquarium with running water, stones and gravel, omitting the sand because I thought it would make it too difficult to locate the tiny eggs. But I found I could not tamper with Nature's design for the survival of a species. No spawning occurred. I then conformed to the natural pattern by adding sand in one corner, and within five minutes the fish had spawned in it. As a rule it is the higher forms of fish which are the more fixed in their conditions for a certain kind of behavior, so it was remarkable that as primitive a fish as the lamprey held fast to "no sand, no spawning."

Hatching takes place in one to two weeks. The wiggling newly hatched are carried by the stream to the first pool, where they promptly take up their abode in the mud.

The soft mud of nearly all streams in the Pacific Northwest contains great numbers of these little eyeless, eel-like, toothless larvae known as ammocoetes. The streams near Seattle, seat of the University of Washington where I went to teach in 1928, were therefore full of promise for a young professor who wanted to know more about lampreys and how they grow. With a dipnet lined with fine-meshed bobbinet I excavated quantities of silt, and in the silt were quantities of ammocoetes. In the mud of Evans Creek, near Richmond, Washington, I once marked off a circle three feet in diameter and lifted its surface foot onto the bank. Therein I found my particular equivalent of grains of gold in panned sand; one hundred and seventy-five ammocoetes in all stages of growth.

Curious as to how these lampreys behaved, I took some of them back to the laboratory and placed them in an aquarium with mud at its bottom. Immediately when one was released in the water it swam a short distance, then erected its body and burrowed head downward with a rapid vibratory movement. Soon it stopped its descent, turned horizontally, and curved upward, forming a burrow in the shape of a flattened U. It stopped burrowing when its mouth was just below the surface.

Unlike adult lampreys the ammocoetes are not adapted for attachment. They feed upon the microscopic plants and animals which drift in the water and among debris at the bottom. Their rate of growth is slow: it takes them three or four years to reach a length of six inches. At that size, usually in autumn, they metamorphose; eyes and teeth form, although they remain jawless.

As adults they continue to live in their muddy stream-bed homes until they are ready to migrate; then, as their parasitic relatives go down to the sea, they go to near-by riffles. The age-old cycle of individual birth and death is unbroken, but species perpetuation continues: they spawn and they die, as their parents have spawned and died before them, and the eggs they have laid will hatch, and the ammocoetes will grow, and metamorphose, and spawn and die, too.

Man cannot alter the spawning and other habits of fishes. But he can, and sometimes does, capitalize upon his knowledge of them to enlarge the supply of fishes in streams, lakes and seas.

14

FISHES CONTROLLABLE BY MAN

For the past few decades the same principles of management that have been applied to domestic animals for many years have been applied to fishes. As farmers have learned to keep the number of sheep in a flock, for example, proportionate to available food supply; to construct shelters for the animals; to fertilize and improve the soil where they graze so there will be more grass; to breed selectively, and to cut down mortality by immunizing against diseases or treating them, so are we just beginning to learn to husband our fish in a scientific and business-like way.

We still have a long way to go in intelligently conserving and increasing our natural stocks of game and commercial fishes. Only a handful of states provide man-made aides to fishes' food supply and their natural productivity, check the fish population by scientific sampling methods, or plant fish in their streams and lakes. But we have made a hopeful start.

Methods of Fish Management in Streams

With the objective of increasing the number of certain fishes in streams, a number of ingenious methods, all based on knowledge of the fishes' habits, are used.

So that salmon and trout may more easily migrate upstream, barriers are removed or fishways and fish-ladders are built.

So that young seaward migrants, going downstream, will not be lost in irrigation and power diversions, screens are installed.

Hiding places where fishes will be safer from enemies are constructed. These shelters are made with logs, brush or log-rafts, or additional pool areas are created (Figure 75). The latter also help in increasing food supply: algae form in still waters, and aquatic insects multiply under stones and in protected places.

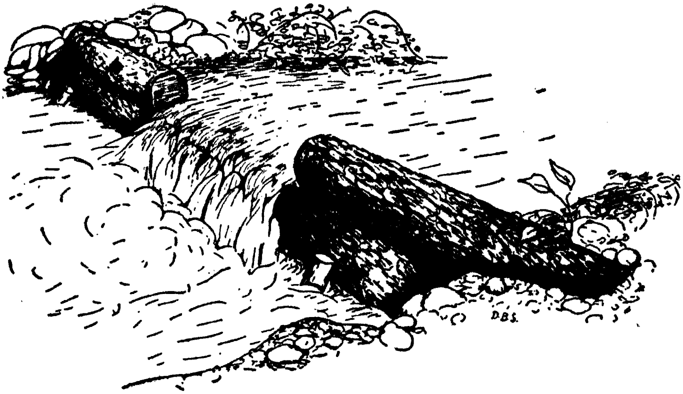

FIG. 75. A low log dam built across a stream deepens the water above it and the water excavates a deep pool below, in which stream fishes find shelter.

Another aid to the food supply is provided by stopping excessive erosion along banks; hence shifting sands and silt are reduced.

Man even has it within his power to step up fishes' reproduction by adding new or enlarging existing spawning areas; riffles for some fishes, weedy places for others.

Finally, an expensive measure but also an effective one, dams are built to ensure an even flow of water and to prevent the washing out of other improvements.

A dramatic instance of man's management of fish in big rivers was the reduction of a serious obstruction to the upstream passage of a commercially valuable salmon. In 1913 the annual great migration of sock-eye salmon swimming and jumping their way to their spawning ground up the Fraser River, British Columbia, was blocked by a landslide, the result of dynamiting, and innumerable fish died without having laid their eggs. Since these deceased salmon had no descendants to return to the ancestral home, and the offspring of salmon originating elsewhere consistently returned to their own birthplace, for many years, even after the river was again flowing freely, its waters were depopulated.

In 1913, 2,000,000 cases of high quality salmon meat had been taken—it would be worth $45,000,000 at 1947 prices. The failure of the salmon to return in the cycle year of 1917 was a commercial disaster, so with international co-operation between the United States and Canada, investigators went out into primitive regions, braving bears, contacting Indians, to tag salmon and discover where the run had been cut off.

After eight years' study they found out that migration was checked where water flowed so swiftly, churned so violently —between water levels of twenty-five and forty feet—the fish could not fight their way through its cascading torrents. The construction of a series of concrete baffles, to slow up swiftly flowing water, and the planting of new spawning stock, resulted in an increase of certain runs in 1946 two to five times over 1942. In addition, so that enough spawners to ensure maintenance of stock will migrate to their breeding grounds, fishing is prohibited after a certain number of salmon have been taken. With all of this man-stimulated new lease on life, the cycle of being hatched in the river system, of going out to sea during adult life, and of returning again to the river to spawn, should be recurring as regularly as the seasons.

Methods of Fish Management in Lakes

In lakes, too, relatively small fluctuation of the water level is desirable, so that food-furnishing aquatic plants have a chance to grow well. Dams are sometimes built in lakes.

Man-made brush, raft and stone shelters create additional protected places for the young.

The establishment of suitable spawning areas for the "forage fishes" upon which game fishes feed increases the available supply of food.

In both streams and lakes young fish, or fish of a size ready to be caught as game fish are planted.

Methods of Fish Management in the Sea

Obviously it is a much more difficult and complex matter to "plant" fish or to construct improvements in the hundreds of thousands of square miles where there are marine fisheries than it is within the confines of a lake or stream. In the sea, man's control of fishes is limited to preventing their decimation and to making sure that natural reproduction will keep pace with the mortality caused by fishermen. In order to accomplish this the marine fishes' habits must be thoroughly understood; no simple attainment, for you cannot study them by standing in a riffle or peering through the glass of an aquarium. The story of how man tackled the problem of the decrease in halibut, became familiar with this fish's ways and brought the supply under control, is outstanding in the annals of conservation.

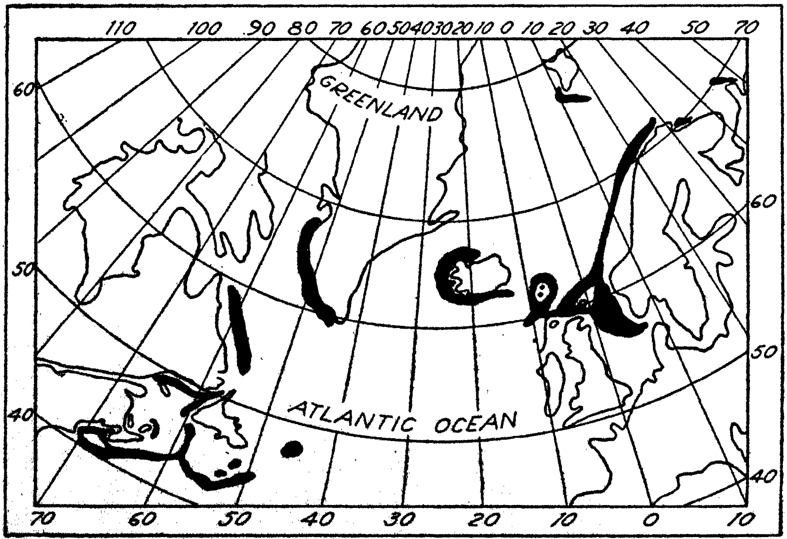

FIG. 76. The solid black indicates the important halibut fishing grounds in the North Atlantic. (Modified after Thompson and Van Cleve.)

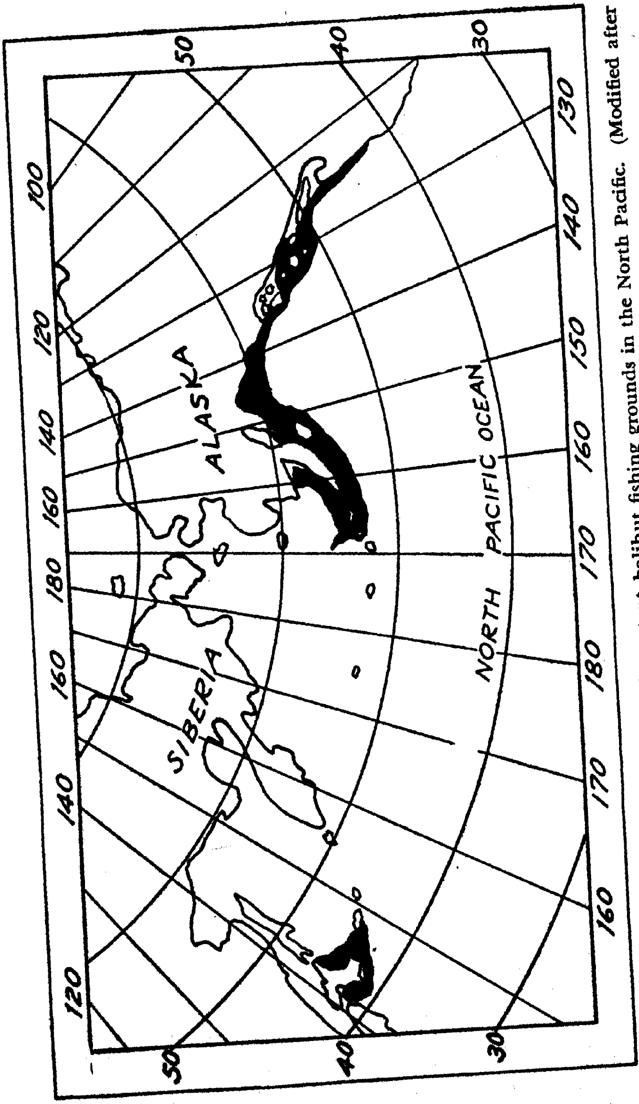

Fig. 77. The solid black indicates the important halibut fishing grounds in the North Pacific. (Modified after Thompson and Van Cleve.)

The Control of the North Pacific Deep-Sea Halibut

There are two species of halibut, the North Atlantic and the North Pacific (Figures 76 and 77), both living in the open sea on the submerged banks of the continental shelf to depths of a few hundred fathoms and at water temperatures of three to eight degrees Centigrade (37° to 48° Fahrenheit). Although the Atlantic fishery probably covers a greater area than the Pacific, it is not as important commercially.

Also, two nations are concerned with the problem of maintaining a supply of Pacific halibut sufficient to make its fishing profitable: Canada and the United States. So, on October 21, 1924, alarmed by the decimation of this commercially valuable fish, the two countries jointly established and financed the International Fisheries Commission for the Study of the Pacific Halibut, under the direction of Dr. Will F. Thompson.

Every halibut fisherman could testify that year by year he had been taking fewer fish and smaller poundage for the same expenditure of fishing effort. It remained for the Commission to establish precisely how disastrous the decline in halibut population had become. Taking as the unit of measurement an hour's catch per gear, or skate—a line about two thousand feet long with baited hooks attached every nine to thirteen feet—it discovered that the catch had dropped from nearly three hundred pounds in 1906 to fewer than fifty in 1930 (Figure 78).

Members of the Commission knew that fishes have some natural mechanism that causes them to reproduce faster during periods of increased mortality. Here, however, with the enormous mortality caused by man's fishing, births of the species had evidently fallen far behind deaths. The Commission now faced the great task of determining how many pounds of halibut could safely be removed from the sea each year without depleting the stock beyond the point where reproduction would balance losses.

It started its investigation by tagging throughout the halibut's known range. Some of the tagged fish were re-captured in chartered boats, but most were recovered by fishermen, who were paid $1.00 per tag returned.

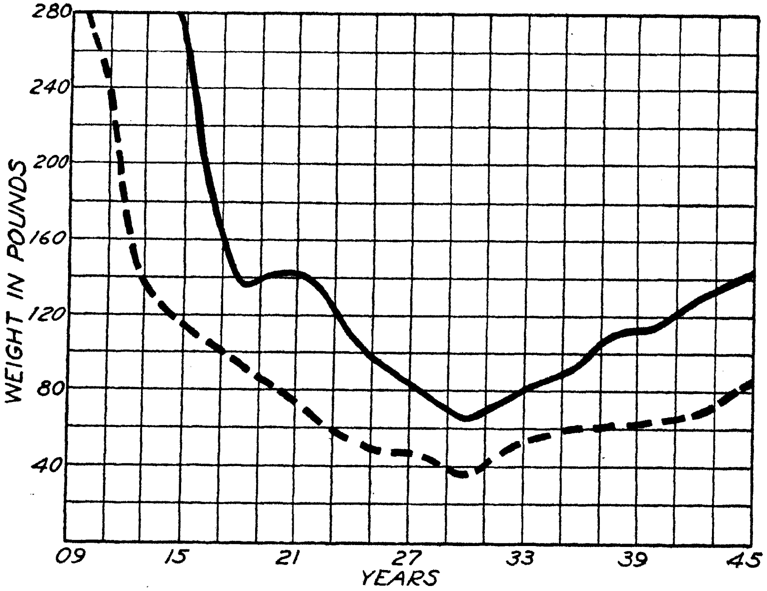

FIG. 78. The commercial catch of Pacific halibut per unit of fishing effort, the skate is shown by the broken line for the area south of Cape Spencer, Alaska, and by the solid black line north of Cape Spencer. After management began in the early thirties the rate of catch per skate increased. (From data published by International Fisheries Commission, Seattle.)

Now, in order to learn the life history of the halibut, age and growth had to be studied. It is more difficult to tell a halibut's age by the usual method of counting annual growth rings on scales than it is with certain other fishes, for the scales are tiny and the rings so close they can scarcely be told apart. Happily, however, there is another part of the fish where Nature keeps age records. It is the otolith, a bony structure that, suspended with nervous connections in the inner ear, serves as a guide for maintenance of equilibrium. New growth, faster in summer, slower in winter, occurs around the edges of the otolith; crystals of calcium carbonate are laid down seasonally, distinguishable as definite summer and winter patterns by a difference in their content of organic matter. The winter growth of the otolith is translucent and the summer opaque white (Figure 79). In a large halibut, the otolith may be as long as an inch, and can easily be read under a low-powered microscope.

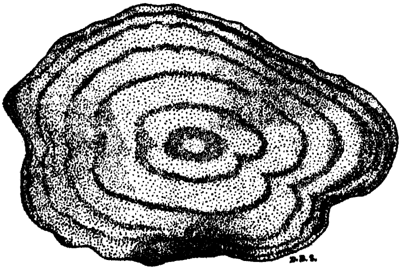

FIG. 79. The otolith, or ear bone, of the halibut is used for age determinations. The slow growth period is translucent and the summer growth opaque light shaded in this figure.

After about ten years of tagging and otolith reading a number of facts about the growth of halibut were established. The males grow more slowly than the females and never weigh more than forty pounds. The females commonly reach a weight of two hundred pounds, with a maximum of four hundred reported. Maturity in the females occurs at the age of twelve. Halibut may reach the age of thirty, possibly more. At such ages the otolith, like the rest of the fish, grows so slowly it is difficult to read.

In the possession of all this material about age, the Commission, on the basis of recovered tagged fish, could mathematically estimate the annual decrease in relative numbers in each age group. In the older age groups this reached appalling proportions, as much as sixty percent, and of course these commercially desirable larger fish were the breeders on whom replenishment depended. The high mortality among spawners had been offset in part by the more favorable feeding and survival conditions enjoyed by a sparser population, but not sufficiently to restore balance. The Commission now, therefore, rules on the number of pounds of mature fish that may be taken.

There is more to marine fisheries management, however, than calculating the number of spawners needed to maintain the population and limiting the legal catch. If the young are not also protected, in time there will not be any mature fish to take, legally or illegally. Before the Commission made its studies it was not known where the larval halibut occurred nor, indeed, even the location of the spawning grounds. Today the migration of the North Pacific halibut in the Gulf of Alaska is as well known as the migration of the eels.

Using circular nets such as those in which leptocephali are caught, the Commission's staff picked up eggs and larvae. They also made extensive studies of certain ocean currents and, piecing their findings together with their tagging records, were able to make as detailed a report of the goings and comings of both adult and larval halibut as a detective makes when he shadows a suspect.

The halibut migrates westward across the Gulf of Alaska to spawn. When it reaches the Kodiak Islands, from the middle of December to the last of March, it deposits its eggs at a depth of one hundred and fifty fathoms. The eggs are pelagic, that is, drift with the current. As with all species having pelagic eggs, and given no parental care, they are produced in great numbers to make up for the perils of the sea, such as their consumption by fish and other marine animals, for they are part of the plankton. A twelve-year-old female may produce 200,000 to 500,000 eggs; a twenty-year-old about 2,750,000, and older and larger fish still more.

Pelagic, or free-floating, too, are the larvae, which slowly develop as they travel with the eddy that circles the Gulf of Alaska counterclockwise. At first, like most pelagic fish larvae, they are transparent. During the fourth or fifth months of their lives and their journey, they lose their transparency and take on pigmentation (Figure 80). At the same

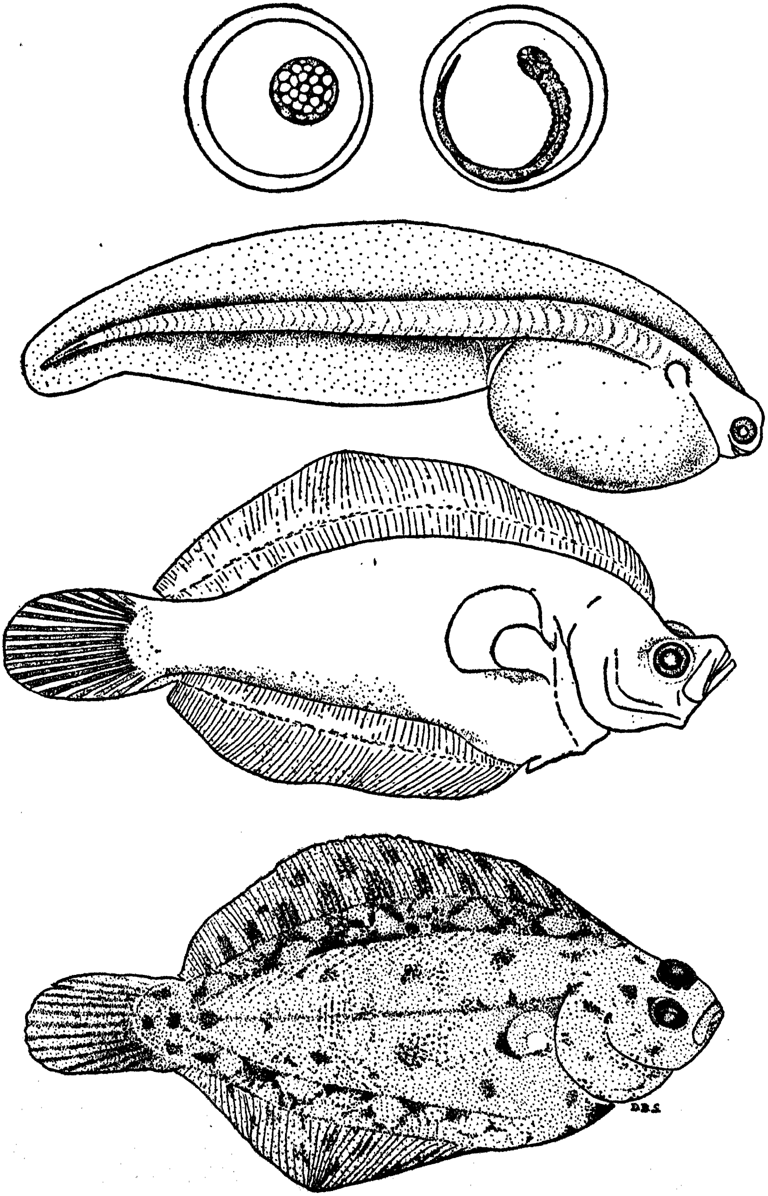

Fig. 80. The halibut larva passes through a metamorphosis in which the left eye moves over to the right side of the head. This adapts the fish for a bottom life. (Modified after Thompson and Van Cleve.)

time, the left eye which hitherto has been normally placed, together with the snout begins to move over to the right side of the head. Thus the young halibut are prepared for bottom life, like the skates and other flat fishes, well before they begin to live it (Figure 80).

About the sixth or seventh month, just at the time the larvae arrive at the shores of British Columbia and Alaska—another instance of Nature's wondrous correlation of time, place and development—they metamorphose and rise to surface waters. There more rapid currents carry them to nursery grounds, shallow shore waters or even shallow waters of sandy beaches of the Queen Charlotte Islands and in southeastern Alaska. Some are carried right around back to the Kodiak Islands.

While they are sexually immature, that is, before they reach the age of twelve, the halibut do not wander very far but, seeking deeper and deeper waters, mill about the banks. The Commission has closed certain areas, such as the nursery grounds, to fishing.

Coast Guard patrols see that the provisions of the Commission are enforced, confiscating the catch and boats of any violators. As a whole, however, halibut fishermen, realizing the importance of conserving the supply of fish out of which they make their living, are quite co-operative. Today the whole halibut situation is so well under control that by taking sampling countings of the number of young fish arriving on the nursery grounds and comparing it with the stock already there, Commission experts can predict how many fish of commercial size there will be in ten to twelve years.

Not enough time has elapsed since the Commission began its work for man's depredations to have been fully restored, but the prospect is hopeful. The International Fisheries Commission for the Study of the Pacific Halibut is undertaking a great biological experiment, and testing the ability of man to learn enough about the habits of fishes to perpetuate species and rationally to exploit them commercially. Not only those who profit financially by their work, but also all of us interested in fishes, respect and applaud their grand-scale achievements and their planning.

In areas measurable in inches rather than in miles, for purpose of entertainment rather than commerce, for hours, even minutes, instead of years, the ways of fishes may also be learned by those who will.

15

HOME AQUARIA: THEIR A B C'S

IT IS a truism that the more you bring to something the more you get out of it, and as a specialist on fishes I have the fun of having the whole world as my aquarium. Wherever there are waters, be they as near by and accessible as Chesapeake Bay on whose shores I summer or as remote as lakes and rivers in the interior of South America, I am blessed with a background that makes me thoroughly enjoy observing and studying fishes and their ways.

I am not, however, suggesting that everyone needs to become a full-fledged ichthyologist in order to share some of the pleasures and interests that are mine. Neither is it necessary to make lengthy journeys by air, land and sea, in conveyances comfortable and uncomfortable, nor to camp out for long periods, to become acquainted with even rare, tropical fishes. Happily any amateur can set up a world of the waters in microcosm by means of a home aquarium and, without moving from an armchair in his living-room, at his leisure and pleasure be an eye-witness of the droll or graceful movements of fishes and their various fascinating doings.

A home aquarium may be as simple as a small glass bowl standing on an occasional table or as elaborate and large as a series of murals set in a specially designed, heated and illuminated room. Its fishy population may range in number from one or two to hundreds, and their cost from nothing, if the specimens are collected in local waters, up through dime-store goldfish all the way to fish priced at four figures.

It is not surprising that marketing aquaria and their contents has become a flourishing business. Few hobbies are as adaptable to the individual's pocketbook and energies or as rewarding with as little time and trouble—perhaps only a few hours a week.

The maintenance of a successful fresh-water aquarium requires basically little more than a following of the principles of "the balanced aquarium." This is one in which natural conditions are simulated, and the relationships among fishes, other animals and plants are balanced as they are in nature. Once established the balanced conditions of an aquarium very largely maintain themselves. About all the aquarist has to do is supply food and water as it evaporates.

Oxygen

Fishes need oxygen, just as man does, although they absorb it in a different way and from a different element. They breathe by taking in water through their mouths and forcing it out past their gill filaments, through their gill slits. Like our lungs, gills are abundantly supplied with a network of minute blood vessels that keep the blood in close contact with oxygenated water.

Water gets its oxygen by absorbing it from the air. Adequate surface area is therefore essential in an aquarium, since this is the only part of its water in direct contact with the oxygenating element. The usual minimum requirement is about eight to ten square inches of surface per inch of fish. For tropical fishes, however, twenty square inches of surface per inch of fish is recommended in most cases. Actually fishes that live in warm waters have less oxygen available than those that live in cold waters. The warmer the water the less readily it absorbs oxygen and the less it contains.

The depth of water in an aquarium has no effect on its oxygen-absorbing capacity, but depth does affect its distribution. The first inch or two of water in a deep aquarium may contain ample oxygen yet it may take hours or even days for it to diffuse down to the bottom. Consequently, if an aquarium is more than six to ten inches in depth the fish in it are likely to take to the surface, trying to breathe in the surface film of water. One reason goldfish survive even the not-so-tender mercies of school children and thrive under adverse conditions is because they are well adapted to breathe that surface film. So are their carp relatives, whom I have seen under natural conditions in South Dakota, the sole survivors in drying-up pools, their backs out of water and the sun beating down upon them. There is no reason, however, for the home aquarist to submit any of his fishes to such punishment! Rule One in aquarium keeping is: Have only enough fish in your aquarium so that all their oxygen needs can be met by the air surface of the water. To depend upon anything else is much too risky.

Nevertheless, there are two supplementary means of supplying oxygen in an aquarium. One is by artificial aeration. The other, the natural way, is through the use of plants.

Plants

Aquatic plants are essential in an aquarium. Their roots absorb waste products from the bottom. Both floating and rooted plants, through the process of photosynthesis, convert the carbon dioxide exhaled by fishes into food for themselves and in return liberate oxygen. In a strong light the green chlorophyll in their leaves does this so vigorously that not all the oxygen can be absorbed by the water, and with the naked eye one can see tiny bubbles rising from the plant.

In the dark, however, photosynthesis stops, and then plants as well as fishes use up oxygen from the water in their constant process of respiration. Although you may increase your fish population a little through the use of plants, you must be sure that there is an ample store of oxygen without depending on their services, or you may get into trouble through their using it up at night. I made that mistake once myself. I was keeping some little pumpkin-seed sunfish in my office, and I let the plants in the aquarium grow and grow until it was almost filled with them. Then one sad Monday morning which followed a weekend of cloudy days and hot humid nights, I walked in and found everything in the aquarium dead—including the plants that had helped to do the damage. In a balanced aquarium there should be no more than one plant for about every four to eight square inches of bottom.

Light

Obviously, if an aquarium is too much in the dark, its plants will not perform their healthful oxygen-supplying work through photosynthesis. A rule of thumb test for the danger point of dimness is: "Is the place where my aquarium stands so dark that I can't read fine print in it?" If the answer is yes, provide more light, either daylight or artificial. A forty-watt electric light bulb kept burning close to the water's surface eight to ten hours a day turns the trick very nicely.

On the other hand, avoid constant exposure to a glare of sunlight. For one thing your aquarium may become overheated; for another you will have the nuisance of having continually to clean the inside walls of your aquarium in order to see your fishes, for a mass of little one-celled algae will spread over the glass sides. North light is excellent and is sufficient for growth of aquatic plants.

Temperature

Most aquarium fishes stay healthy in a room temperature kept fairly constant at seventy-two degrees Fahrenheit. If an aquarium is covered, the water in it is at about room temperature; if uncovered, it is likely to become a little cooler because of evaporation.

Certain tropical fishes cannot stand water which is cooler than seventy degrees; to be safe, have it at a reasonably constant seventy-five. These higher temperatures may be maintained by thermostatically controlled electric heaters manufactured especially for aquarists' use with tropical fishes.

The majority of fishes, however, can tolerate a range of ten to fifteen degrees, so if their water temperature does not change too rapidly they will not suffer from something like a five-degree drop overnight. Many of the more hardy fishes from temperate regions can withstand increasing cold nearly down to the freezing point; but even these may be killed by an abrupt drop in temperature. It is as hard on fish to have a quantity of cold water poured into their aquarium all at once as it is on a human to fall through the ice!

Feeding

Err on the side of feeding too little at a time, rather than too much. When there is uneaten food in an aquarium it becomes suspended in the water or sinks to the bottom and the water becomes cloudy and unlovely. Worse still, bacterial action and decomposition set in; the bacteria use oxygen, the oxygen supply becomes depleted, and fish and plants may die. Feed only as much as is consumed as it is placed. Feeding two to four times a day in a warm aquarium is not too often as long as all the food is promptly devoured.

A change of food items stimulates fishes' appetites as it does those of people. Prepared natural fish foods, such as dried Daphnia or shrimps, are good. Still better, because it comes closer to natural conditions, is the introduction of living foods such as Tubifex worms, Daphnia, Cyclops and infusoria. This method has the further advantage of being self-replenishing. A living food supply takes care of itself because it reproduces.

Other Animals

Certain small animals are useful in aquaria not as food, but as scavengers. Snails, such as the small, brown pond snail, *Physa,* eat debris at the bottom, and also make excellent window cleaners because they feed on the one-celled algae likely to besmear glass sides. They lay their eggs in little jelly-like masses, and as the elder snails die off they are replaced by young ones. Should any snail corpses not be eaten by the fish, they decay and are absorbed by the plants and one-celled algae. Usually there is little need to worry about either under- or overpopulation of snails, because they live and die in direct proportion to the amount of food available.

It is inadvisable to leave snails in a tank with spawning fishes for they may eat the fish eggs.

Hazards

The aquarist must be careful not to introduce any undesirable animals. Aquatic insect larvae such as those of the water tiger, dragon fly, back swimmers, water boatmen and diving beetles, albeit they may make good eating when they are very small, grow up into dangerous killers. Some of these insects have a venomous bite, some suck blood. Another enemy of fishes to avoid is the fresh-water *Hydra,* one of the coelenterates that digests tiny fishes after stinging them to death.

Plants carry hazards too, for if they are taken from ponds or streams and are not sterilized before they are placed in an aquarium, they may bring in fish diseases and parasites. One of the commonest fish diseases is known as "Ich"—short for *Ichthyophthirius,* which shows up as white specks on fins and bodies. It is caused by a protozoan that burrows just below the outer skin. A white pimple is formed, and in this, using the body fluids of the fish, lives the little parasite. In a few days the protozoan matures, breaks out, forms a cyst around itself and drops to the bottom, where it shortly produces one or two thousand young. It does not take long for the entire population of an aquarium to become infected with Ich, which is usually followed by the fatal fungus disease, *Saprolegnia,* which attacks the wounds of *Betta.*

If any other diseases occur an expert should be consulted. There are fish pathologists, specialists on the diseases of fishes, just as there are veterinarians, qualified to diagnose and treat the diseases of cattle or dogs.

Since the remedies for fish diseases are uncertain and difficult to apply, it is the better part of valor not to introduce any food or plants likely to carry infection. Your best course is to buy plants expressly grown for aquarium purposes.

Changing Water

The rule here is delightfully simple, although emphatic: Don't!

In addition to maintaining plants and animals, for some unknown reason biologically conditioned water—that is, the water in a balanced aquarium—after several months has a cleansing and healing effect should the fish in it suffer minor injuries. It has even been reported on fairly good authority that such water has a healing effect on certain skin diseases and infections of man. At any rate, a newspaper writeup of the phenomenon at one time made the New York Aquarium a veritable Mecca for the afflicted. Perhaps the effect of biologically conditioned water on man is something like that of penicillin, but I am not a physiologist and I shall not venture to say.

I do, however, know the salutary effects of biologically conditioned water on fish, so recommend without hesitation that for the most part, once the healthy state of its inhabitants has convinced you of its balance, you leave your miniature watery world severely alone except for feeding and occasionally siphoning of debris from the bottom. Add fresh water only to replace evaporation of an inch or two. A glass cover will slow up the process of evaporation.

My Balanced Aquarium

In 1936, when I came to the United States National Museum, I inherited a rectangular, steel-framed aquarium, its glass sides sealed with aquarium cement. It was about two feet long, one foot wide, and one foot high, and I set it up with the idea of balancing it. My objective was not to create a showpiece to be the wonder and envy of my colleagues, but the more modest one of demonstrating how simply and inexpensively the amateur could go and do likewise.

From a small creek near my home, I obtained some bottom sand. First I washed out all the clay so that the water in my aquarium would not be cloudy. Next, by putting the remaining sand into one of my wife's cooking pans and baking it, I sterilized it, in order to kill off any parasites that later might wreak havoc among my fishes.

After placing the sand about three inches deep in the bottom of my aquarium and after obtaining some disease-free aquatic plants from a friend, I planted a couple of dozen clumps of eel grass and a few stalks of Elodea, fastening the plants with a few prettily colored stones. I then poured rainwater into the aquarium until it was about eight inches deep, thus covering the plants. I did not use the city water as it contained too much chlorine.

Next I covered the aquarium with a piece of plate glass, and placed my tank about two yards away from a window where the sun never shone into it directly. I maintained room temperature at a constant seventy-two degrees Fahrenheit and after about two weeks, without any further care, the plants were well established and there was a faint growth of algae on the side nearest the window. I then added some duckweed, a floating plant, and considered the tank ready for my animals to move in.

My fish were four small *Corydoras,* one of the South American catfishes. They are slow-moving, deliberate little scavengers who rove about the bottom seeking bits of food and dead animal and plant matter settling there. Because I did not have much time to devote to my aquarium, I did not bother with a mixed population of fishes which might require more attention.

To keep clean the greenish side of my aquarium I introduced a dozen snails to feed on the algae. They made most of their eggs safe from the *Corydoras* by laying them along the sides.

As food I put in at regular intervals bits of dried shrimp and living Tubifex worms. I did not touch my aquarium except to feed the fish and add water whenever there was an inch or so evaporation. At the end of the second year, my original quartette of *Corydoras* were all alive and active and had doubled in size; my other animals were neither too many nor too few, and my plants were healthy. Although unspectacular, my aquarium was definitely balanced, so I wrote it off as a success.

Any more ambitious—and hence more interesting and diverting—aquarium will, of course, have a more heterogeneous population. The selection of aquarium inhabitants from among about a thousand possibilities is one of the delights of the hobby.

16

FISHES SUITABLE FOR AQUARIA

Not every fish is suitable for a home aquarium. All marine fishes are out for the amateur, because maintenance of a salt-water aquarium is so complicated chemically and physiologically it requires a specialist. Obviously some fishes are too large to fit comfortably into any container that must, in turn, fit comfortably into a home. Other fishes require an environment undesirable to reproduce. Muddy or stagnant water, for instance, is no esthetic asset in a living room.

The aquarist must also consider who is to live with whom. Predators should not be placed in an aquarium with smaller non-predators. Likewise fishes with a tendency to nibble fins or nip off tails do not make good neighbors.

Nevertheless, an amazing variety of fishes—members of only a few families—can live happily together, and thrive and breed in confinement. Some are our own local fishes. Others have been imported from all over the world, except from the coldest regions. Formerly they took long voyages in ships, with caretakers en route; now they are speedily transported by air. The most interesting ones are native to Central and South America, India, China and Africa, but many aquarium fishes are not immigrants. They are bred especially for aquarium purposes.

Generally, fishes are selected for aquaria and are popular for their beauty, or their interesting habits. Sometimes, besides, aquarium fish can be taught to come for food or even to perform tricks. There is a tale of goldfish who ordered their meals by tugging a string attached to a tiny bell. Carp in an outside pool learned to jump out onto the edge of the bank where food was placed.

Goldfish and their varieties, cultivated for centuries in China, are perhaps the most familiar form of aquarium life. But the aquarist who keeps only goldfish is on a par with a physician who gives no other medicine but aspirin.

To describe in detail the appearance, characteristic and habits of all the potential denizens of aquaria would require volumes. In suggesting the richness of choice available to the home aquarist, I shall therefore restrict myself to a brief identification and Who's Who of some of the aquarium fishes with such notes on their looks, behavior, place of origin and family connections as will interest the hobbyist or help him to make his selections when he goes shopping or collecting.

Fishes Suitable for Aquaria (listed in their evolutionary order)

Pantodon, a fresh-water flying fish, is known to most aquarists as the butterfly fish, although this common name really belongs to a group of gorgeously colored marine reef fishes. Blackish on its back, silvery on its sides and underneath, it is native to tropical West Africa. Equipped with immense pectoral and other large fins, living near the surface, it is able to skim two yards, and unless its aquarium is covered is likely to land on the floor when it is excited. Its habits are nocturnal. *Pantodon's* nearest relatives are the bony-tongued fishes, the Osteoglossidae, primitive fishes occurring in South America and Southeastern Asia.

From among about one thousand kinds of characins in the Americas and hundreds of others in Africa, aquarists have selected some two hundred that live happily in aquaria. Among them are:

Copeina, named after the great American naturalist, Edward Drinker Cope. Generally this three-or-four-inch Brazilian fish is covered with contrasting bright red, black, and white spots. Its anal and pelvic fins are reddish; the tips of the lower lobe of its caudal fin are red. The dorsal fin of the female has a red spot. At the base of the male's dorsal fin is a bright white spot that contrasts sharply with the black just in front of it. During the breeding season males and females, spawning in water a little above ordinary room temperatures, carry on a courtship evidenced by tremblings. The eggs are deposited in little jelly-like masses placed above the reach of most fishes on solid objects a bit above the water line. Probably unique among fishes is the male's habit of keeping the eggs moist by splashing water on them with his fins at fifteen or twenty minute intervals. The eggs hatch in about three days. *Copeina* may be fed worms, insect larvae and daphnia.

There are several kinds of *Astyanax,* most of them no longer than four inches, all things of beauty. They are silvery, with diffuse yellows to reds on the sides. Their anal and sometimes their dorsal fins are tinged with red or orange; their backs are brownish to blackish; the middle rays of their caudal fins are yellowish with the lower lobe red; their pectoral fins are yellowish, their pelvic fins pinkish. Usually the middle rays of their tail fins and caudal peduncle are marked with a blackish elongate blotch and their shoulders have a distinctive black spot. For all their delicate pastel coloration, these fishes are hardy and active. They are also peaceful and live well with other fishes. They occur as far south as Argentina and are the only members of their family extending as far north as New Mexico.

Similar in nature to *Astyanax* are *Hemibrycon, Hemigrammus, Moenkhausia, Hyphessobrycon* and a dozen other related fishes. Still others are called tetras from the generic name *Tetragonopterus.* Perhaps the most colorful of them all is red tetra or flame fish *(Hyphessobrycon flammeus),* native to Brazil. Reaching a maximum length of half an inch, it is ideal in an aquarium because of its congeniality with other fishes, longevity—about four years, and most small fishes live no more than one or two—and brilliant coloration. Its general color is scarlet, breast silvery, head iridescent yellow and green, with two lancet-shaped black bars behind it. A pale greenish streak extends along its upper side. Its back is brick color and the rear of its sides bright red. So are the tail fin, anal fin, dorsal and pelvic fins; the anal fin is edged with black, the pelvic fins tipped with it. The front of the dorsal fin is black, edged with white. The males are easily recognizable by the small paired spines, hook-like denticles, on the rays of their anal fins. Pairs of this fish spawn in thick growths of aquatic plants: little groups of eggs adhere to the leaves. The eggs hatch in three days and the babies may be fed infusoria. The female seems to have the instinct of parental care only a short while after the eggs are laid but the male has it from a few days to a few weeks. Then, like the female, he turns cannibalistic, so it is advisable to remove the adults to another aquarium.

The fresh-water hatchet fishes (such as the ones I found in Venezuela), *Pterodiscus, Thoracocharax, Carnegiella* and *Gasteropelecus,* are fascinating to watch because of their flying habits. For the same reason they require a large aquarium. It is difficult to breed them in captivity.

Mylossoma, Colossoma, and *Metynnis,* which range from the Maracaibo Basin in Venezuela to Argentina, are related to the piranha and have the same sunfish shape, but amiable dispositions like the Tetras'. They are lively fishes. A few are voracious, others are vegetarians. Some have the lower parts of their bodies yellow, some pink, with the backs dusky-greenish and their sides silvery. Their median fins are pink to red.

The small darter-like *Characidium* differs from the rest of the characins suitable for aquaria in how and where it lives. Although it occurs in most South American streams it prefers running water among gravel and stones, in hilly to mountainous regions. Breeding males of the *Characidium chupa* of Venezuela reach a length of four inches. The *Characidium* has small teeth. In coloring, the body is a pastel yellow. There are three bright yellow spots on the sides of the head, the gill covers are brown-blotched, the dorsal fin yellowish-orange crossed by two blackish streaks. Wavy, blackish vertical bars run along its sides. It is a bright sight in clear running water; when I came upon a small, pellucid stream in the foothills of the high Andes in Venezuela I watched these little fishes darting here and there. They would come to rest occasionally on their slightly elevated pectoral fins, their heads motionless; then they would dart so fast to another spot my eye could not follow them. Only by the little cloud of sand stirred up sometimes a yard away, when they had stopped sharply, could I tell where they had alighted. Little is known about these fishes' breeding habits.

The two hundred odd characins used as aquarium fishes belong to one of the largest groups of fresh-water fish families, that great order including minnows, carps, catfishes and gymnotid eels. A peculiarity of this order, invisible except under dissection, is the way the first four vertebrae are modified to form a chain of bones connecting the air bladder with the ears. Most characins have adipose fins similar to those found on salmon, trout and whitefishes. They have evolved nearly every type of structure, and occupied nearly every type of habitat in their range—Central and South America, and Africa. Some live in the lowlands, some in mountain streams, some in quiet ponds and ditches and others, like North American darters, hide in gravel and among stones. In temperament also, they vary widely. Some are predaceous and bloodthirsty—notoriously the piranha—many are docile and retiring. Some characins are as small as an inch, others as large as two feet. Although characins resemble minnows and carps, the aquarist can easily distinguish them: they are well-toothed, whereas minnows and carps are toothless.

Gymnotid eels are not true eels, and are more appropriately called Cuchillos (knife-fishes) by the Spanish. Related to the characins and catfishes, they are distinguishable by their knife-like shape. The anal fin, thin as the cutting edge of a knife, extends from below and just behind the head to the tip of the tail. Some gymnotid eels have no dorsal or tail fins. Their eyes are very small and they have nocturnal habits. Much of the time they exhibit the oddity of swimming backwards. These fishes are hardy, can live under adverse conditions, and are voracious eaters. Naturally they prefer muddy and weedy bottoms, and occur from Central America southward to Argentina. They should not be confused with the African and Asiatic knife-fishes of similar appearance. These belong to an entirely different order and family called Notopteridae, and, although they might also be used in aquaria, have not yet been taken up by aquarists.

Several of the carps and minnows (family name, Cyprinidae), are rated among the most attractive aquarium fishes. *Danio, Brachydanio, Barbus, Rasbora, Esoma, Daniops, Hampala* and several others from the Malay States, Siam, India and China make desirable aquarium fishes because of their beautiful high coloration. In North America, among others, the chief aquarium fishes of this family are *Notropis, Clinostomus, Rhinichthys,* and *Chrosomus.* All are egg-layers.

Chrosomus erythrogaster, the red-bellied dace, requires an elaborate set-up to spawn in captivity. During the breeding season the males are the most brilliantly colored fish in North America. They have vivid scarlet stripes along their sides and bellies and small red spots just behind the jaws on each side. The smaller females have the same kind of coloration, but it is fainter. The males, like the majority of fresh-water fishes, especially carps and minnows, during the breeding season develop little bony protuberances, resembling pearls and called nuptial tubercles, on their bodies, heads, tails and fins. Living in small, flowing brooks, during mid-May to mid-June schools of red-bellied dace congregate in pools. Then, several males pursuing one female, they swim up a riffle. As the foremost gain positions alongside the female, their speed is almost lightning-like. Then a male presses against each side of a female, the positions maintained both by the stones between which the fish squeeze and by the nuptial tubercles. The trio faces upstream and vibrates rapidly for an instant, during which the eggs are laid and fertilized. The males immediately relax their hold. The eggs adhere to bottom pebbles. Many stream fishes breed similarly.

The whole school is a moving mass of red in the water. I have observed this fish spawning under natural conditions. By approaching the stream cautiously, I could see and hear water splashing on shallow rapids, its cause the fish struggling and crowding on one another in waters so shallow the surface became violently agitated. Occasionally a mass of wriggling fish would flash into view at the surface, then crowd onto the pebbly shore, where a few would be left stranded until they managed to wriggle back into the water. If alarmed, almost invariably they would swim upstream from the shallows into deeper water where they would gradually recover from their fright; then, before reaching shallow water again, would face about with eddying movements and swim upstream. Following this pattern of fright behavior, each time they would come back a little closer. Gradually, like a flock of sheep moving in unison, the whole red mass surged slowly upstream.

The average home aquarist could not duplicate the natural conditions to make his *Chrosomus erythrogaster* spawn in an aquarium, but if it has been caught in a stream it will have its vivid coloration during the breeding season. Since it is a temperate water fish it is satisfactory and picturesque in an outdoor pool.

The whole group of carps and minnows occur in temperate North America, Europe, Asia, India, Africa, and islands southeast of Asia as far east as Java and Borneo. There are none in South America or Australia or the tropical islands of the Pacific Ocean except as they have been introduced by man. Minnows vary in length from an inch to over eight feet; the largest in North America is the squaw fish, which lives in western rivers. These fishes never have adipose fins like the characins and catfishes. Unlike most fishes they have no teeth in their jaws; but the pharyngeal bones far back in their throats usually have teeth of the crushing type; these press against the flat bony pad at the base of the skull.

Loaches, native to Asia, are related to minnows and carps, but differ from them in having three or four pairs of barbels around their mouths. Most of them have a general coloration of pale pink to tan and olive and are barred with black or brown. They burrow in mud or stones and are usually scavengers. They defend themselves with erectile spines under and before their eyes. Seldom exceeding a length of five inches, they are hardy and can endure a wide range of temperature and poor aquarium conditions. They get along well with other fishes. Loaches belong to such genera as *Botia, Lepidocephalus,* and *Noemacheilus.*

Catfishes, or Siluridae, occur in salt and fresh waters all over the world and have been divided into more than a dozen families. They are scaleless or covered with bony plates. Most of them have an adipose fin. Several pairs of long barbels occur around the mouth and on the chin. Any of the North American catfishes, even mad toms, do well in an aquarium. They are hardy and eat almost anything, such as bits of meat, aquatic insects and worms.

Corydoras, of the family Callichthyidae, are the most widely used aquarium catfishes. Smooth-armored three-inchers, they make good members of an aquatic community. Native to South America, they live largely in muddy places in quiet waters. During the egg-laying act, when the male and female come together, the female holds out her pelvic fins and a few eggs become attached to them. Then she swims to a plant leaf and presses the eggs against it; they are viscous, and adhere. Upon hatching, the young seek bottom debris and live in it for a few weeks.

The two-to-three-inch-long Bunocephalidae, their bodies partially covered with little plates, live naturally in streams. Interesting to aquarists is the way the eggs cling to the undersides of the parents; they are held in place, apparently, by the pelvic fins. The heavy-bodied South American Doradid catfishes have one or more rows of spines along their sides. Their chief aquarium appeal is their ability to grunt.

Perhaps most curious of the catfishes that can be kept in an aquarium is the African electric catfish *Malapterurus*. This nocturnal, rather sluggish, predaceous fish is a voracious eater and may live for several years, ultimately reaching a length of three feet. Because its electric charge is strong enough to make a man jump, it must be housed alone.

Toothed carps are more universally used in aquaria than any other group of fishes, because of their small size, adaptability to small tanks, beautiful coloration, and activity. In addition, some kinds are easy to breed. There are two families of them, one egg-laying, the other live-bearing. The fishes whose common names are killfishes or top minnows, so-called because they swim at the surface, are egg-layers. The most common American types are *Fundulus, Cyprinodon, Lucania, Rivulus, Cubanichthys* and *Jordanella. Aplocheilus* hails from southern Asia, and *Aphyosemion, Panchax* and *Epiplatys* from Africa. All these fishes do very well in aquaria and can live on prepared and live food such as shrimps, worms and insect larvae. *Jordanella* subsists largely on algae.

Among the live-bearers, the most extensively found in aquaria are *Gambusia* and *Lebistes.* They are carnivorous and nibble fins, so that few other fishes can be kept in the same tank with them. *Gambusia,* native to the southeastern United States from Delaware to Florida and south to Tampico in Mexico, has been introduced into tropical waters for mosquito control. *Lebistes'* common name is guppy, in honor of Lechmere Guppy of Trinidad, who first collected it. It occurs in Venezuela to the Guianas and Trinidad. Guppies are active, thrive in close quarters, eat almost anything and can tolerate a temperature range of sixty-five to one hundred degrees Fahrenheit. But these are only a few of the reasons they are so popular with aquarists. They are one of the most beautifully colored of the live-bearing toothed carps, and each gorgeous male is identifiable as an individual for no two are alike in their bright coloring. Many aquarists give their guppies personal names. The males have bright ocellate spots, black surrounded with bright colors, yellow, green, orange, red, lavender and purple.

Both guppies and *Gambusia* breed rapidly and their spawning habits are easily observed. The first three rays of the males' anal fins are modified into a pointed, grooved, rod-like projection, called the gonopodium, which is carried parallel and close to the body, pointing backward. In courting, the male grandly spreads all his fins like a peacock flaunting his tail, and excitedly approaches the female, usually a little from the rear or parallel. He may circle her without her paying any attention—she appears to be neither flattered nor interested. When he is in an advantageous position, he makes a quick thrust with the gonopodium which can be promptly moved at right angles, forwards or sideways, and with uncanny precision inserts its tip in the egg duct of the female, delivering a charge of milt. Several weeks later, the young are born fully developed and at once begin to swim.

Other commonly used live-bearers are *Platypoecilus, Mollienisia, Limia, Girardinus, Quintana,* and *Xiphophorus,* or sword-tails. Both sexes of *Xiphophorus* look alike when young but when the male matures the lower rays of his tail fin elongate to form a long, colored spike. These fishes have been domesticated and bred for color variety; there may, for example, be a green body with an orange or green spike, a yellow or red-orange body with a black-edged yellow spike. The males have a jumping habit and their aquarium should be covered.

Mud minnows, as the name indicates, love muddy bottoms and weedy ponds, hiding much of the time among weeds. The mud minnow *Novumbra,* which I described in 1929, has been found only in the vicinity of Satsop, Washington, in the Chehalis River drainage. It is little used in aquaria because of its rarity, but I know that it makes a good aquarium fish because I kept some *Novumbra* alive for months, until the glass of their aquarium was shattered by accident. They were active and fed voraciously on worms and insect larvae. They were interesting to watch in a characteristic pose of resting obliquely in the water, in sculling fashion moving only their pectoral fins. During the February breeding season these fish are the most gorgeously colored of their group. They have black vertical bars alternating with pea green that changes to a yellow with a silvery green iridescence. Their fins are barred with blacks, greens, electric blues and ocher; their eyes have vertical black bars; their gill covers are tipped with emerald green topped by black and a center of iridescent gold, and their gill membranes are contrasting bluish black and dull yellowish orange. These fishes breed in ditches and shallow ponds among the weeds of flooded meadows that dry in summer. They are an archaic type with only two known relatives in eastern North America, one in Central Europe, and one in Alaska and across the Bering Strait in Siberia. Mud minnows are representatives of an ancient fish fauna that extended across the North American continent prior to the elevation of the Rocky Mountains, and of which fossil remains have been found in the Eocene Green River Shales of Wyoming. Two of the living relics of that fauna, in addition to *Novumbra,* live in Western streams; a Percopsid, the trout perch in the Columbia River of Washington and Oregon, and a bass in the San Joaquin and Sacramento River systems of California.

Sticklebacks are interesting both for their ability to lock erected spines and for their parental habits. They occur in all temperate and sub-arctic regions of the Northern Hemisphere in fresh, brackish and salt water, and should never be kept in water warmer than seventy-five degrees Fahrenheit. The group is recognizable by its two to fifteen or more dorsal spines, without any connecting membrane, in front of a soft dorsal fin. Sticklebacks are seldom longer than three inches. The kinds most commonly used in aquaria are *Gasterosteus* and *Apeltes.*

Aquarists find it simple and fascinating to observe sticklebacks' nesting. As early spring approaches the males' kidneys become swollen posteriorly, where a glandular mass of cells secretes glue. This is voluntarily extruded, insoluble in water, and very sticky when first secreted. The male passes and repasses leaves of aquatic plants, pulling them together, holding and fastening them by tough fine threads of his glue, until he has constructed a nest with a tubular opening at each end. It is advisable not to have too many males in the same aquarium, for the stickleback's naturally bellicose tendency is intensified during the breeding season and he fights every intruder into his domain, especially if it be another male, rushing at him with the speed of an arrow and striking with his sharp pelvic spines. After several such rushes, the stronger fish signals his triumph by a show of splendid colors, and sometimes by extension of the territory he guards. No monogamist, he successively induces a number of females into his nest, and then, immediately after mating, drives each away with rapid darts. He remains with eggs and nest, with his fins fanning currents of water to oxygenate them. Males in near-by nests tend to fight. One will sneak up quietly on another and, as soon as the invader is spotted, the defender will erect his spines. The first may retreat, then give a return rush toward his opponent in an unguarded moment, and biting or jabbing will ensue. When the battle is over both males continue to tend their own nests. When the young are hatched, should any of them straggle from the nest, the father, who has continually been ventilating it, picks up his baby in his mouth and replaces it. Since any immature sticklebacks that wander from their father's domain are quickly devoured by adult sticklebacks, perhaps even their own mothers, the fathers have good reason to fight.

Perches, sunfishes, and basses, easily collected from streams and able to live at ordinary room temperatures, grow rapidly on a diet of worms, shrimp or prepared fish foods. If well fed, certain kinds may grow two to three inches during the first year. They make desirable aquarium fishes because of their coloring. *Lepomis gibbosus,* whose common name is the pumpkin seed sunfish—actually it is several times larger than a pumpkin seed—has a gaudy array of iridescent reds, purples and greens. It lives in ponds, lakes and streams, and prefers clear water with aquatic plants. It will breed in an aquarium no smaller than three feet long and a foot and a half high. Under natural conditions the males take on added coloration in early spring and by May excavate nests under plants and are ready to spawn. Sunfishes and basses occur in North America. Even some of the game basses make good household pets when they are young and until they reach a pound or so in weight, and they do well outdoors. Yellow perch occur in eastern North America and Europe. None of these fishes should be put with guppies or other small fishes because they are predaceous.

Anabantids, which rise frequently to the surface to breathe air, include the walking perch, *Betta* and gouramis occurring in ponds, ditches and streams of Africa and southeastern Asia. Convoluted tissues in an extra gill chamber—called a labyrinth—above the gill arches, are richly supplied with capillary blood vessels that absorb oxygen from the air when an air bubble, taken into the mouth, is swallowed into the labyrinth. Nearly all labyrinth fishes—*Anabas,* the walking perch, is not one of these—are bubble-nest builders and are therefore doubly entertaining in an aquarium.

Most widely used Anabantids are *Betta* and *Macropodus,* the paradise fish, which has been an aquarium favorite for centuries. Fully as beautiful and graceful as *Betta,* it has the merit of being less pugnacious; nevertheless, it is inadvisable to keep two males of *Macropodus* in the same aquarium. The related forms *Anabas, Trichogaster,* and the gourami, *Osphronemus,* all occurring in southern and southeastern Asia and the East Indies, are also popular aquarium fishes. *Helostoma,* the kissing gourami, has lips curving backward. Their specifically adaptative purpose is eating algae off stones, but they are used a large part of the time for kissing and sucking other *Helostoma.* There is no sexual significance in this osculation; apparently it is merely a sociable gesture. The kissing gourami will even kiss its own image if a mirror is held in its aquarium.

The spiny-rayed Cichlids, related to the damsel fishes of tropical reefs, occur in Africa, Madagascar, the southern tip of India, and in the Americas from the Rio Grande of Texas to southern South America. The greatest variety are in Africa and Central America. They range in size from a few inches to a foot. In general, when adult, they do not make good community fishes. Nevertheless, their reproductive habits are so distinctive and amusing they are popular with aquarists. They need more space for breeding than many other fishes of their size because there must be room for retreat when they quarrel during courtship. An aquarium six feet square is satisfactory. The water should be at least seventy-five degrees Fahrenheit. When a male and a female cichlid have paired off, by diligent biting and fanning they clean off an area of sand where there is some hard surface. Before the eggs are deposited in it, the female develops a tube at her vent called an ovipositor; she lays the eggs and the male fertilizes them. Several hundred eggs are placed and fertilized in a few hours; a delicate sense of touch in the ovipositor packs them closely and as they are adhesive they stick fast to some hard surface in the nest. Both male and female remain with the nest and alternately fan it for cleansing and oxygenating purposes. The eggs hatch in a few days, and both parents remove the young and place them in a newly cleaned spot in adjoining sand. This process of cleaning and moving continues at intervals from a few days to two weeks, each time with the meticulousness and immaculateness of a Dutch housewife. The parents are fearless in protecting their young. After two weeks the young swim with the parents in a compact school; should there be any stragglers they are gathered in and put back with the school. The family instinct lasts until the young are so active that the parents can no longer manage them—aquarists with adolescent children will have a special appreciation of this situation!

In a state of nature, nest-building cichlids pair off without any difficulty, but in an aquarium, a male and a female may fight and damage each other unless both are ready to mate. It is a common practice to separate the sexes with a glass plate so they can do some preliminary flirting through the window. Either male or female may be the first to spread the fins and make a display of orange and green coloration. If the other indicates approval and responds similarly, it is probably safe to remove the transparent barrier between them. When they continue to be pleased with each other, they lock their lips, pulling and twisting, in what appears to be a contest of strength. But when love turns to hate, and one retreats from the kisses, a fight is on to the death. The resultant fatality to one or the other may be nature's way of eliminating the unfit.

Undoubtedly the mouth breeding of some cichlids, such as *Haplochromis, Tiliapia,* and *Pelmatochromis,* has evolved from nest building. With these, the male prepares the nest. The female lays eggs about the size of mustard seeds and quickly takes them in her mouth. During the entire several days' period of incubation, the female does not eat, and if she is caught will hold her mouth tightly shut. When the eggs are hatched, the young at first leave the maternal mouth only for short periods, but when they grow larger, they can no longer be held in such "protective custody."

Cichlids commonly used in aquaria are the South American *Cichlasoma* or Jack Dempsey, and the West African *Hemichromis. Aequidens,* from South America, resembles sunfish in shape and some of its habits.

Most distinctive in appearance of all the Cichlids, most widely found in aquaria is *Pterophyllum,* the angel fish. Its long, wing-like fins with projecting tips are banded black and white. In nature the eggs are deposited on leaves or stems; in an aquarium, any opaque object, such as painted glass tubes, may be substituted. Upon hatching the young remain attached by a sticky thread to where the eggs were laid. Like a human infant kicking its legs, they vibrate their little tails for exercise and oxygenation purposes. At intervals the parents may pick them up and spew them onto another leaf where the thread reattaches itself. After a few days the young become detached and swim off.

These few facts about the wonders and beauties of aquarium fishes and their lives have been intended only to indicate the potential delights of maintaining a home aquarium. And if, throughout this entire book, I have managed merely to suggest the fascination of the teeming watery world which my colleagues and I make our life work to explore, it will have served its purpose.

Appendix

CLASSIFICATION OF FISHES

The following classification of fishes has been prepared from the study of recent publications of revisions of genera, families, and higher groups of fishes. It represents the conclusions reached by several dozen ichthyologists, both living and dead. Among active ichthyologists, practically no two agree upon the arrangement of the various categories of classification.

Such disagreement is a healthy condition in the field of ichthyology, because it indicates that new facts are being discovered and these change the conceptions of relationships, thus altering the arrangement of the orders and families of fishes. Our knowledge is too imperfect to arrange the groups in a truly natural classification.

In any outline of classification, such as the present one, it is not possible to indicate close relationships among fishes when arranged in a linear series as is necessary in our modern methods of printing. However, the present arrangement expresses as nearly as is practical the general evolutionary relationships of the various families.

In accordance with general custom, the most ancient, simplest or most primitive types are listed first followed by a sequence of orders and families ending with the most highly specialized recent forms.

It will be noted by ichthyological students that certain families are not recognized that were listed in Jordan's *Classification of Fishes* published in 1923 by Stanford University. Most of these have long been combined with well-known families by capable investigators, and a few are included in parentheses following the currently recognized name of the family.

Living groups are in boldface type, and fossil groups in italics. The endings for families are *idae;* for orders and suborders, *oidea* for words with Greek roots, and *iformes* for words with Latin roots. The = sign following a group name means that those groups included in parentheses are synonymous with the recognized group name.

- Phylum **Chordata**
  - Subphylum **Acrania** (without cranium)
    - Class **Cephalochordata** (= **Leptocardi**)
      - Order **Branchiostomoidea**
        - Family **Branchiostomidae** (Lancelets)
  - Subphylum **Craniata** (= **Vertebrata**; with cranium)
    - Superclass **Agnatha** (without jaws)
      - Class *Cephalaspidomorphi*
        - Order *Osteostracoidea*
          - Family *Cephalaspididae* (= *Sclerodidae Thyestidae;* upper Silurian to upper Devonian)
          - Family *Dartmuthiidae* (= *Didymaspiidae;* upper Silurian)
          - Family *Tremataspididae* (upper Silurian)
          - Family *Oeselaspididae* (upper Silurian)
        - Order *Anaspidoidea*
          - Family *Birkeniidae* (= *Pharyngolepididae, Pterolepididae, Rhyncholepididae;* upper Silurian)
          - Family *Euphaneropididae* (upper Devonian)
          - Family *Lasaniidae* (upper Silurian)
          - Family *Endeiolepididae* (upper Devonian)
      - Class **Marsipobranchii** (= **Cyclostomata**)
        - Order **Petromyzonoidea**
          - Family **Petromyzonidae** (Anadromous; temperate fresh waters; Lampreys)

- Class *Pteraspidomorphi*
    - Order *Heterostracoidea*
        - Family *Poraspididae* (= *Ctenaspididae, Dinaspidellidae; Dinaspididae; Americaspididae; Palaeaspididae; Irregulareaspididae; Dictyaspididae;* and *Anglaspididae;* upper Silurian to lower Devonian)
        - Family *Cyathaspididae* (= *Tolypelepidae; Tolypaspididae; Diplaspididae;* and *Traguairaspididae;* upper Silurian to lower Devonian)
        - Family *Pteraspididae* (upper Silurian to lower Devonian)
        - Family *Drepanaspididae* (= *Psammosteidae; Weigeltaspididae;* upper Ordovician to upper Devonian)
        - Family *Amphiaspididae* (lower Devonian)
        - Family *Astraspididae* (incertae sedis) (Ordovician)
    - Order *Coelolepidoidea*
        - Family *Thelodontidae* (= *Coelolepididae; Phlebolepididae* and ? *Paraplesiobatidae;* ? Ordovician to ? upper Devonian
- Class **Myxini**
    - Order **Myxinoidea** (Hagfishes; temperate seas)
        - Family **Eptatretidae**
        - Family **Myxinidae**
        - Family **Paramyxinidae**

Incertae sedis under **Agnatha**—

- Order *Euphaneroidea*
    - Family *Jamoytiidae* (Silurian)

Superclass **Gnathostomata** (= **Pisces**; with jaws)

- Class *Placodermi* (= *Aphethyoidea)*
    - Order *Acanthodioidea*
        - Family *Brachycanthidae* (= *Climatiidae, Euthacanthidae, Parexidae;* lower Devonian)

- Family *Diplacanthidae* (upper Silurian to upper Devonian)
- Family *Ischnacanthidae* (? upper Silurian to middle Devonian)
- Family *Gyracanthidae* (lower Devonian to Pennsylvanian)
- Family *Mesacanthidae* (lower Devonian to upper Devonian)
- Family *Acanthodidae* (= *Cheiracanthidae;* lower Devonian to lower Permian)
- ? Family *Onychodontidae* (lower Devonian to upper Devonian)

Order *Arthrodiroidea* (= *Coccostei)*
  - Suborder *Euarthrodiroidea*
  - Suborder *Arctolepida* (= *Acanthaspida; Acanthothoraci*)
    - Family *Phlyctaenaspidae* (= *Arctolepidae, Polyaspidae;* upper Silurian to middle Devonian)
  - Suborder *Brachythoraci*
    - Family *Coccosteidae* (middle Devonian to upper Devonian)
    - Family *Selenosteidae* (upper Devonian)
    - Family *Homosteidae* (middle Devonian to upper Devonian)
    - Family *Heterosteidae* (middle Devonian to upper Devonian)
    - Family *Titanichthyidae* (upper Devonian)
    - Family *Holonemidae* (middle Devonian to upper Devonian)
    - Family *Hadrosteidae* (upper Devonian)
    - Family *Leptosteidae* (upper Devonian)
    - Family *Trematosteidae* (upper Devonian)
    - Family *Brachydiridae* (upper Devonian)
    - Family *Oxyosteidae* (upper Devonian)
    - Family *Synauchenidae* (upper Devonian)

- Family *Mylostomidae* (upper Devonian)
- Family *Pachyosteidae* (upper Devonian)

Suborder *Ptyctodontoidea*

- Family *Ptyctodontidae* (middle Devonian to upper Devonian)

Suborder *Phyllolepoidea*

- Family *Phyllolepidae* (upper Devonian)

Order *Macropetalichthyoidea* (= *Petalichthyida*)

- Family *Macropetalichthyidae* (lower to upper Devonian)

Order *Antiarchoidea* (= *Pterichthyes*)

- Family *Asterolepididae* (= *Microbrachiidae* and *Bothriolepididae;* middle to upper Devonian)
- Family *Byssacanthidae* (= *Ceraspididae;* middle to upper Devonian)
- Family *Remigolepididae* (upper Devonian)

Order *Stegoselachioidea*

Suborder *Stensioelloidea*

- Family *Stensioellidae* (lower Devonian)
- ? Family *Cratoselachiidae* (lower Carboniferous)

Suborder *Rhenanoidea* (= *Gemuendini*)

- Family *Gemuendinididae* (lower to upper Devonian)

Order *Palaeospondyloidea*

- Family *Palaeospondylidae* (middle Devonian)

Class Elasmobranchii (= Chondrichthyes; Cartilaginous fishes; sharks, rays and skates)

Subclass *Xenacanthi* (= *Pleuracanthodii, Ichthyotomi*)

Order *Xenacanthoidea*

- Family *Xenacanthidae* (lower Carboniferous to lower Permian)

- Subclass *Cladoselachi* (= *Pleuropterygii*)
  - Order *Cladoselachoidea*
    - Family *Cladoselachidae* (= *Cladodontidae* in part, ? *Tamiobatidae;* upper Devonian to lower Carboniferous)
    - Family *Ctenacanthidae* (in part; middle Devonian to Pennsylvanian)
- Subclass **Selachii** (= **Euselachii, Plagiostomi**; Sharks and rays)
  - Superorder **Selachoidea** (= **Pleurotremata**)
    - Order **Heterodontoidea**
      - Family *Coronodontidae* (= *Deneidae;* upper Devonian to lower Mississippian)
      - Family *Tristychiidae* (Mississippian)
      - Family *Hybodontidae* (= *Ctenacanthidae* in part; upper Devonian to Cretaceous)
      - Family *Edestidae* (in part; Mississippian to Permian)
      - Family **Heterodontidae** (= *Palaeospinacidae;* **Cestracionidae**; lower Jurassic to Recent; Bullhead sharks)
    - Order **Hexanchoidea** (= **Notidanoidea**)
      - Family **Chlamydoselachidae** (Miocene to Recent; Frilled sharks)
      - Family **Hexanchidae** (Middle Jurassic to Recent; Cow sharks)
    - Order **Lamnoidea**
      - Suborder **Galeoidea**
        - Family **Orectolobidae** (upper Jurassic to Recent; Carpet sharks)
        - Family **Rhincodontidae** (= **Rhineodontidae**; Whale sharks)
        - Family **Odontaspididae** (= **Carchariidae**; upper Cretaceous to Recent; sand sharks)
        - Family **Isuridae** (= **Lamnidae**; Cretaceous

to Recent; mackerel sharks; man-eaters; mako shark)
- Family **Alopiidae** (Tertiary to Recent; thresher shark)
- Family **Cetorhinidae** (Oligocene to Recent; basking shark)

Suborder **Scyliorhinoidea**
- Family **Scyliorhinidae** (= **Catulidae**; upper Jurassic to Recent; cat sharks)
- Family **Galeorhinidae** (= **Galeidae**; **Carcharhinidae**; Eocene to Recent; gray sharks)
- Family **Sphyrnidae** (Eocene to Recent; hammerhead sharks)

Order **Squaloidea**
- Suborder **Squaloidea**
  - Family *Protospinacidae* (upper Jurassic)
  - Family **Squalidae** (upper Cretaceous to Recent; dog sharks)
  - Family **Echinorhinidae** (bramble sharks)
  - Family **Dalatiidae**
  - Family **Pristiophoridae** (upper Cretaceous to Recent; saw sharks)
- Suborder **Squatinoidea**
  - Family **Squatinidae** (upper Jurassic to Recent; angel sharks)

Superorder **Hypotremata** (Jurassic to Recent; rays and skates)
- Order **Batoidea**
  - Suborder **Rajiformes** (rays and skates)
    - Family **Rhinobatidae** (upper Jurassic to Recent; guitar fishes)
    - Family **Pristidae** (Eocene to Recent; saw fishes)
    - Family **Platyrhinidae** (= **Discobatidae**; thornback guitar fishes)

Family **Rajidae** (upper Cretaceous to Recent; skates)
Family **Dasyatidae** (= **Trygonidae**; upper Cretaceous to Recent; stingrays)
Family *Ptychodontidae* (lower to upper Cretaceous)
Family **Myliobatidae** (= **Rhinopteridae**; upper Cretaceous to Recent; cow-nosed rays; eagle rays)
Family **Mobulidae** (Tertiary to Recent; devil rays; manta)
Suborder **Narcobatoidea**
Family **Torpedinidae** (= **Narcaciontidae**; lower Eocene to Recent; electric rays)
Class **Holocephali**
Order *Bradydontoidea*
Family *Cochiodontidae* (= *Menaspidae; ? Rhadamantidae;* upper Devonian to upper Permian)
Family *Petalodontidae* .(= *Janassidae;* Mississippian to lower Permian)
Family *Psammodontidae* (Carboniferous)
Family *Copodontidae* (upper Devonian to lower Permian)
Family *Chondrenchelyidae* (Mississippian)
Family *Edestidae* (in part) (Mississippian to Permian)
Order **Chimaeroidea** (ratfishes; elephant fishes)
Family *Squalorajidae* (lower Jurassic)
Family *Myriacanthidae* (lower to upper Jurassic)
Family **Chimaeridae** (lower Jurassic to Recent; chimaeras; elephant fishes; ratfishes)
Family **Rhinochimaeridae**
Family **Callorhinchidae**

Class **Osteichthyes** (bony fishes)
  Subclass **Choanichthyes**
    Order **Dipnoidea** (lung fishes)
      Family *Dipteridae* (= *Dipnorhynchidae;* middle to upper Devonian)
      Family *Phaneropleuridae* (= *Scaumenacidae; Fleurantiidae;* upper Devonian)
      Family *Ctenodontidae* (= *Uronemidae;* Mississippian to lower Permian)
      Family *Conchopomidae* (Pennsylvanian to lower Permian)
      Family **Neoceratodontidae** (Pennsylvanian to Recent; Australian lungfish)
      Family **Lepidosirenidae** (? Pennsylvanian to Recent; South American lungfish)
      Family **Protopteridae** (Oligocene to Recent; African lungfish)
    Order **Crossopterygioidea** (fringed fins)
      Suborder *Rhipidistioidea* (= *Osteolepidoti*)
        Family *Porolepidae* (lower to middle Devonian)
        Family *Osteolepidae* (= *Glyptopomidae; Ectosteorhachidae; Rhizodontidae; Megalichthyidae; Rhizodopidae;* Devonian to Permian)
        Family *Holoptychiidae* (middle to upper Devonian)
      Suborder **Coelacanthioidea** (= **Actinistia**)
        Family *Diplocercididae* (middle to upper Devonian)
        Family *Coelacanthidae* (Mississippian to upper Cretaceous)
        Family *Langiidae* (lower Triassic)
        Family **Latimeriidae** (Southeast Africa; "living fossil")

- Subclass **Actinopterygii** (rayed fins)
  - Superorder **Chondrosteoidea** (cartilage and bone)
    - Order *Palaeoniscoidea*
      - Family *Cheirolepididae* (middle to upper Devonian)
      - Family *Rhadinichthyidae* (middle Devonian to lower Permian)
      - Family *Canobiidae* (Mississippian)
      - Family *Haplolepididae* (*Phanerorhynchidae;* Pennsylvanian)
      - Family *Elanichthyidae* (? upper Devonian to upper Permian)
      - Family *Palaeoniscidae* (*sensu stricto; Casmolepidae; Oxygnathidae;* Pennsylvanian to lower Jurassic)
      - Family *Pygopteridae* (Mississippian to lower Jurassic)
      - Family *Acrolepididae* (Mississippian to lower Triassic)
      - Family *Amblyteridae* (upper Pennsylvanian to upper Permian)
      - Family *Aeduellidae* (lower Permian)
      - Family *Cryphiolepididae* (Mississippian)
      - Family *Scanilepididae* (upper Triassic)
      - Family *Coccolepididae* (lower Jurassic to lower Cretaceous)
      - Family *Dicellapygidae* (? lower Permian to upper Triassic)
      - Family *Birgeriidae* (lower to upper Triassic)
      - Family *Holuridae* (Mississippian)
      - Family *Tarrasiidae* (Mississippian to Pennsylvanian)
      - Family *Boreolepididae* (upper Permian)
      - Family *Trissolepididae* (Pennsylvanian)
      - Family *Tegeolepididae* (upper Devonian)
      - Family *Cocconiscidae* (Pennsylvanian)

- Family *Cornuboniscidae* (Pennsylvanian)
- Family *Styracopteridae* (Mississippian)
- Family *Amphicentridae* (Mississippian to upper Permian)
- Family *Platysomidae* (Mississippian to ? lower Jurassic)
- Family *Dorypteridae* (upper Permian)
- Family *Carbovelidae* (= *Gymnoniscidae;* Mississippian to Pennsylvanian)

Order **Cladistioidea** (= **Polypterini**)

- Family **Polypteridae** (upper Eocene to Recent; lobe-finned Ganoids)

Order **Acipenseroidea** (= Chondrostei in part)

- Family *Chondrosteidae* (lower Triassic to lower Cretaceous)
- Family **Acipenseridae** (upper Cretaceous to Recent; sturgeons)
- Family **Polyodontidae** (upper Cretaceous to Recent; paddlefishes; spoonbills)

Order *"Subholosteoidea"* (an artificial order with forms anatomically intermediate between Chondrosteans and Holosteans)

- Family *Dictypygidae* (= *Redfieldiidae; Brookvaliidae;* lower to upper Triassic)
- Family *Perleididae* (lower to upper Triassic)
- Family *Platysiagidae* (middle Triassic to lower Jurassic)
- Family *Cephaloxemidae* (middle to upper Triassic)
- Family *Peltopleuridae* (upper Triassic)
- Family *Luganoiidae* (middle to upper Triassic)
- Family *Aetheodontidae* (middle to upper Triassic)
- Family *Ptycholepididae* (lower Triassic to lower Jurassic)

        Family *Parasemianotidae* (= *Tungusichthyidae; Ospiidae;* lower to upper Triassic)
        Family *Pholidopleuridae* (lower to upper Triassic)
        Family *Saurichthyidae* (lower Triassic to lower Jurassic)
        Family *Cleithrolepididae* (lower to upper Triassic)
        Family *Bobasatraniidae* (lower Triassic)
Superorder **Holostei** (bone and cartilage)
    Order **Semionotoidea** (= **Lepisostei**)
        Family *Semionotidae* (= *Acentrophoridae;* upper Permian to lower Cretaceous)
        Family **Lepisosteidae** (upper Cretaceous to Recent; gars)
    Order *Pycnodontoidea*
        Family *Pycnodontidae* (= *Gyrodontidae; Coccodontidae;* upper Triassic to upper Cretaceous)
    Order *Aspidorhynchoidea*
        Family *Aspidorhynchidae* (upper Jurassic to upper Cretaceous)
    Order **Amioidea**
        Family *Macrosemiidae* (middle Triassic to upper Cretaceous)
        Family *Caturidae* (= *Eugnathidae;* middle Triassic to upper Cretaceous)
        Family **Amiidae** (= *Sinamiidae;* upper Jurassic to Recent; bowfin)
        Family *Pachycarmidae* (= *Protosphyraenidae;* upper Triassic to upper Cretaceous)
    Order *Pholidophoroidea*
        Family *Pholidophoridae* (middle Triassic to lower Cretaceous)

Family *Archaeomaenidae* (Jurassic to middle Triassic)
Family *Oligopleuridae* (upper Jurassic to upper Cretaceous)

Superorder **Teleostei** (perfected bone)
  Order **Isospondyloidea**
    Suborder **Clupeoidea**
      Family *Lycopteridae* (lower Cretaceous)
      Family *Leptolepididae* (upper Triassic to middle Cretaceous)
      Family **Elopidae** (lower Cretaceous to Recent; bonefish; macabi; tarpons)
      Family **Albulidae** (Eocene to Recent; ladyfishes)
      Family **Pterothrissidae**
      Family *Pseudoberycidae* (lower Cretaceous to Oligocene)
      Family *Syllaemidae* (upper Cretaceous)
      Family *Crossognathidae* (Cretaceous)
      Family **Clupeidae** (lower Cretaceous to Recent; herrings; sardines; shad; alewifes)
      Family **Hiodontidae** (mooneyes)
      Family **Notopteridae**
      Family **Dussumieridae** (= **Stolephoridae**; round herrings)
      Family **Engraulidae** (anchovies)
      Family **Alepocephalidae** (deep-sea fishes)
      Family **Dolichopteryidae** (deep-sea fishes)
      Family **Macristiidae**
      Family *Ctenothrissidae* (upper Cretaceous)
      Family *Ichthyodectidae* (Cretaceous)
      Family *Saurodontidae* (upper Cretaceous)
      Family **Chanidae** (lower Cretaceous to Recent; milkfish)
      Family **Kneriidae** (= **Cromeriidae**; tropical Africa; freshwaters)

- Family **Gonorhynchidae**
- Family *Notogoneidae* (upper Cretaceous)
- Family *Plethodidae* (Cretaceous)
- Family **Osteoglossidae** (= **Arapaimidae; Clupisudidae**; bony-tongued fishes)
- Family **Pantodontidae** (tropical Africa; freshwaters)

Suborder **Salmoniformes**
- Family **Salmonidae** (Eocene to Recent; salmon and trout)
- Family **Coregonidae** (whitefishes)
- Family **Thymallidae** (grayling)
- Family *Thaumaturidae* (lower Eocene)
- Family **Plecoglossidae** (Ayu)
- Family **Osmeridae** (smelts)
- Family **Salangidae**

Suborder **Opisthoproctoidea**
- Family **Opisthoproctidae**
- Family **Macropinnidae**
- Family **Winteriidae**
- Family **Xenophthalmichthyidae**
- Family **Bathylagidae**
- Family **Microstomidae**
- Family **Argentinidae** (deep-sea smelts)

Suborder **Stomiatoidea**
- Family **Gonostomidae**
- Family **Sternoptychidae** (silver hatchet fishes)
- Family **Stomiatidae**
- Family **Chauliodontidae**

Suborder **Gymnophotodermoidea**
- Family **Melanostomiatidae** (deep-sea fishes)
- Family **Idiacanthidae**
- Family **Astronesthidae**
- Family *Tomognathidae* (Cretaceous)

Suborder *Enchodontoidea*

Family *Enchodontidae* (Cretaceous)
Suborder **Iniomoidea**
  Family **Synodontidae** (lizard fishes)
  Family **Aulopiidae**
  Family *Chirothrichidae* (upper Cretaceous)
  Family **Scopelarchidae**
  Family **Evermannellidae**
  Family **Omosudidae**
  Family **Sudidae**
  Family **Alepisauridae** (handsaw fishes)
  Family **Anotopteridae** (deep-sea fishes)
  Family **Myctophidae** (= **Scopelidae**; lantern fishes)
  Family *Rhinellidae* (upper Cretaceous)
  Family *Dercetidae* (upper Cretaceous)
  Family **Cetomimidae**
  Family **Barbourisiidae**
Suborder **Esociformes** (= **Haplomi**)
  Family **Aplochitonidae**
  Family **Galaxiidae**
  Family **Retropinnidae** (incertae sedis)
  Family **Esocidae** (pickerels)
  Family **Dallidae** (blackfish)
  Family **Umbridae** (mudminnows)
  Family **Novumbridae** (western mudminnows)
  Family *Palaeoesocidae* (lower Eocene)
Order **Bathyclupeoidea**
  Family **Bathyclupeidae**
Order **Mormyroidea** (insertae sedis)
  Family **Mormyridae**
  Family **Gymnarchidae**
Order **Ateleopoidea**
  Family **Ateleopidae**
Order **Giganturoidea**
  Family **Giganturidae** (deep-sea fishes)

- Order Lyomeroidea
  - Family Saccopharyngidae
  - Family Eurypharngidae
  - Family Monognathidae
- Order Ostariophysoidea
  - Suborder Characinoidea (= Heterognathi)
    - Family Characinidae (Characins)
  - Suborder Gymnotoidea
    - Family Rhamphichthyidae (knife fishes)
    - Family Sternarchidae (knife fishes)
    - Family Gymnotidae
    - Family Electrophoridae (electric eel)
  - Suborder Cyprinoidea (= Eventognathi)
    - Family Catostomidae (suckers)
    - Family Cyprinidae (carps; minnows)
    - Family Homalopteridae (loaches)
    - Family Gyrinocheilidae
    - Family Cobitidae (loaches)
    - Family Adiposiidae
  - Suborder Nematognathoidea (catfishes)
    - Family Diplomystidae
    - Family Ariidae (= Tachysuridae; marine catfishes)
    - Family Ameiuridae (catfishes of North American freshwaters)
    - Family Doradidae (South American catfishes)
    - Family Ageneiosidae (South American catfishes)
    - Family Pimelodidae (South American catfishes)
    - Family Helogeneidae (South American catfishes)
    - Family Hypophthalmidae (South American catfishes)
    - Family Cetopsidae (South American catfishes)

Family **Pygidiidae** (South American catfishes)
Family **Bunocephalidae** (South American catfishes)
Family **Callichthyidae** (South American catfishes)
Family **Loricariidae** (plated South American catfishes)
Family **Astroblepidae** (South American catfishes)
Family **Clariidae** (Old World catfishes; freshwaters)
Family **Siluridae** (Old World catfishes; freshwaters)
Family **Heteropneustidae** (= **Saccobranchidae**)
Family **Plotosidae**
Family **Pangasiidae** (= **Schilbeidae**)
Family **Amblycepitidae**
Family **Dorichthyidae**
Family **Sisoridae** (= **Bagaridae**)
Family **Bagridae**
Family **Akysidae**
Family **Amphilidae** (African)
Family **Chacidae**
Family **Olyridae**
Family **Mochocidae** (= **Synodontidae**)
Family **Malapteruridae** (African; electric catfish)

Order **Apodoidea** (upper Cretaceous to Recent; true eels)
Family **Anguillavidae**
Family *Mylomyridae*
Family *Urenchelyidae*
Family **Derichthyidae** (long-necked eels)
Family **Anguillidae** (freshwater eels)
Family **Muraenesocidae**

        - Family **Simenchelyidae** (snubnosed eels)
        - Family **Xenocongridae**
        - Family **Myrocongridae**
        - Family **Muraenidae** (moray eels)
        - Family **Heterenchelyidae**
        - Family **Moringuidae**
        - Family **Neenchelyidae**
        - Family **Nettastomidae** (duckbill eels)
        - Family **Nessorhamphidae**
        - Family **Congridae** (conger eels)
        - Family **Echelidae** (= **Myridae**; worm eels)
        - Family **Ilyophidae**
        - Family **Ophichthyidae** (snake eels)
        - Family **Dysommidae**
        - Family **Synaphobranchidae**
        - Family **Nemichthyidae** (snipe eels)
        - Family **Cyemidae**
        - Family **Avocettinopsidae**
        - Family **Macrocephenchelyidae**
        - Family **Aoteidae**
- Order **Heteromoidea** (upper Cretaceous to Recent)
    - Family **Halosauridae**
    - Family **Lipogenyidae**
    - Family **Notacanthidae** (spiny eels)
- Order **Synbranchioidea** (freshwater; mud eels)
    - Family **Alabetidae**
    - Family **Synbranchidae**
    - Family **Amphipnoidae**
- Order **Synentognathoidea**
    - Suborder **Scomberesocoidea**
        - Family **Scomberesocidae** (Sauries)
        - Family **Belonidae** (needlefishes; houndfishes)
    - Suborder **Exocoetoidea**
        - Family **Hemiramphidae** (= **Schindleriidae**; halfbeaks)

- Family **Exocoetidae** (flying fishes)
- Order **Cyprinodontoidea** (= **Microcyprini**; Oligocene to Recent; toothed carps)
  - Suborder **Amblyopsoidea**
    - Family **Amblyopsidae** (cave blindfishes; North American)
  - Suborder **Poecilioidea**
    - Family **Cyprinodontidae** (killifishes)
    - Family **Adrianichthyidae**
    - Family **Goodeidae**
    - Family **Anablepidae** (foureyed fishes)
    - Family **Horaichthyidae**
    - Family **Tomeuridae**
    - Family **Jenynsiidae**
    - Family **Poeciliidae** (viviparous top-minnows)
- Order **Salmopercoidea** (Eocene to Recent)
  - Family **Percopsidae** (trout-perches)
  - Family **Aphredoderidae** (pirate-perches)
- Order **Berycomorphoidea**
  - Family **Stephanoberycidae**
  - Family **Rondeletiidae**
  - Family **Gibberichthyidae**
  - Family **Diretmidae**
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  - Family **Melamphaidae**
  - Family **Polymixidae**
  - Family ***Perycopsidae*** (upper Cretaceous)
  - Family **Berycidae**
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  - Family **Trachichthyidae**
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  - Family *Protosyngnathidae*
  - Family **Indostomidae**
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  - Family **Fistulariidae** (cornet fishes)
  - Family **Macrorhamphosidae** (snipefishes)
  - Family **Centriscidae** (shrimp fishes)
  - Family **Rhamphosidae**
  - Family **Solenostomidae**
  - Family **Syngnathidae** (= **Hippocampidae**; pipefishes; seahorses)
- Order **Allotriognathoidea**
  - Family **Lamprididae** (moonfishes)
  - Family **Veliferidae**
  - Family **Lophotidae**
  - Family **Regalecidae** (kingfishes)
  - Family **Trachypteridae** (ribbonfishes)
  - Family **Stylophoridae**

Order **Percomorphoidea** (perches)
  Suborder **Percesoces**
    Family **Sphyraenidae** (lower Eocene to Recent; barracudas)
    Family **Atherinidae** (= **Melanotaenidae**; silversides)
    Family **Mugilidae** (Oligocene to Recent; mullets)
  Suborder **Phallostethoidea**
    Family **Phallostethidae** (viviparous silversides)
  Suborder **Polynemoidea** (= **Rhegnopteri**)
    Family **Polynemidae** (threadfins)
  Suborder **Anabantoidea** (= **Labyrinthici**)
    Family **Anabantidae** (= **Osphronemidae**; lower Tertiary to Recent; walking or climbing perch; fightingfishes)
    Family **Luciocephalidae**
  Suborder **Channoidea** (= **Ophicephaloidea**)
    Family **Channidae** (= **Ophicephalidae**; serpent-head fishes)
  Suborder **Percoidea**
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    Family **Centropomidae** (= **Chandidae**; **Ambassidae**; Cretaceous to Recent; robalos)
    Family **Kuhlidae** (= **Nannatherinidae**)
    Family **Apogonidae** (= **Cheilodipteridae**; **Scombropidae**; Eocene to Recent; cardinal fishes)
    Family **Centrarchidae** (Eocene to Recent; sunfishes; freshwater basses)
    Family **Serranidae** (= **Epinephelidae**; Eocene to Recent; sea basses; groupers)
    Family **Pseudochromidae** (= **Plesiopidae**; reeffishes)
    Family **Glaucosomidae**

Family **Priacanthidae** (Eocene to Recent; big-eyes; catalufas)
Family **Sillaginidae**
Family **Branchiostegidae** (= **Latilidae**; tilefishes)
Family **Malacanthidae**
Family **Labracoglossidae**
Family **Lactariidae**
Family **Pomatomidae** (Miocene to Recent; bluefishes)
Family **Rachycentridae** (sargent fishes; crab-eaters)
Family **Carangidae** (Eocene to Recent; jacks)
Family **Menidae** (Eocene to Recent)
Family **Nematistiidae** (peacockfish)
Family **Bramidae** (upper Miocene to Recent; pomfrets)
Family **Coryphaenidae** (dolphins)
Family **Arripidae**
Family **Lutjanidae** (lower Oligocene to Recent; snappers)
Family **Emmelichthyidae** (= **Centracanthidae**; pelagic snappers)
Family **Pomadasyidae** (Eocene to Recent; grunters)
Family **Nemipteridae**
Family **Sparidae** (Eocene to Recent; porgies)
Family **Lethrinidae** (pigfishes)
Family **Teraponidae**
Family **Lobotidae**
Family **Gerridae** (= **Leiognathidae**; mojarras)
Family **Sciaenidae** (upper Cretaceous to Recent; croakers; drumfishes)
Family **Mullidae** (surmullets)

- Family **Pempheridae**
- Family **Enoplosidae**
- Family **Dichistiidae**
- Family **Polycentridae**
- Family **Nandidae**
- Family **Toxotidae** (Tertiary to Recent; archer fishes)
- Family **Scorpididae** (halfmoon fishes)
- Family **Girellidae** (greenfishes)
- Family **Kyphosidae** (rudder fishes)
- Family **Oplegnathidae** (= **Hoplegnathidae**)
- Family **Monodactylidae** (= **Psettidae**)
- Family **Chaetodontidae** (Eocene to Recent)
  - Subfamily **Chaetodontinae** (butterfly fishes)
  - Subfamily **Pomacanthinae** (spiny butterfly fishes)
  - Subfamily **Ephippinae** (spadefishes)
- Family **Platacidae**
- Family **Scatophagidae**
- Family **Zanclidae** (moorish idols)
- Family **Acanthuridae** (Eocene to Recent; surgeon fishes; tangs)
- Family **Siganidae**
- Family **Cichlidae** (Eocene to Recent; mojarras)
- Family **Pomacentridae** (lower Eocene to Recent; damsel fishes)
- Family **Embiotocidae** (Eocene to Recent; viviparous perches; surffishes)
- Family **Labridae** (lower Eocene to Recent; lipfishes; wrasses; hogfishes)
- Family **Scaridae** (= **Callyodontidae**; Eocene to Recent; parrot fishes)
- Family **Neoodacidae** (rock whiting)
- Family **Gadopsidae** (river blackfish)
- Family **Cirrhitidae**

- Family **Chironemidae**
- Family **Aplodactylidae**
- Family **Cheilodactylidae**
- Family **Latridae** (trumpeters)
- Family **Trichodontidae** (sandfishes)
- Family **Opisthognathidae** (jawfishes)
- Family **Owstoniidae**
- Family **Bathymasteridae** (ronquills)
- Family **Mugiloididae** (= **Pinguipedidae; Parapercidae**; sand perches)
- Family **Cheimarrhichthyidae**
- Family **Trachinidae** (= **Callipterygidae**; lower Eocene to Recent
- Family **Percophidae**
- Family **Bembropidae** (= **Pteropsaridae**)
- Family **Trichonotidae** (= **Hemerocoetidae; Creediidae; Limnichthyidae**; sand-divers)
- Family **Oxudercidae**
- Family **Henicichthyidae**
- Family **Leptoscopidae**
- Family **Dactyloscopidae** (sand stargazers)
- Family **Uranoscopidae** (stargazers)
- Family **Champsodontidae** (= **Centropercidae**)
- Family **Chiasmodontidae** (swallowers; deep-sea fishes)
- Family **Bovichthyidae**
- Family **Nototheniidae** (Antarctic blennies)
  - Subfamily **Nototheniinae**
  - Subfamily **Chaenichthinae**
  - Subfamily **Bathydraconinae** (dragon fishes)

Suborder **Blennioidea** (= **Jugulares**; blennies)

- Family **Anarhichadidae** (wolf fishes)
- Family **Blenniidae** (tropical blennies)
- Family **Congrogadidae**
- Family **Notograptidae**

- Family **Clinidae** (scaled blennies)
- Family **Pholididae** (northern blennies)
- Family **Stichaeidae**
- Family **Microdesmidae** (burrowing blennies)
- Family **Scytalinidae** (burrowing blennies)
- Family **Ptilichthyidae** (quillfishes)
- Family **Xenocephalidae**
- Family **Peronedyidae**
- Family **Ophiclinidae**
- Family **Zoarcidae** (eel pouts)
- Family **Derepodichthyidae**
- Family **Zaproridae** (highbrows)

Suborder **Ophidioidea**
- Family **Brotulidae** (upper Eocene to Recent)
- Family **Ophidiidae** (upper Cretaceous to Recent)
- Family **Fierasferidae** (= Carapidae; Eocene to Recent; pearl fishes)

Suborder **Ammodytoidea** (lower Oligocene to Recent)
- Family **Ammodytidae** (sand lances)

Suborder **Callionymoidea** (dragonets)
- Family **Callionymidae** (upper Miocene to Recent)
- Family **Draconettidae**

Suborder **Trichiuroidea**
- Family **Gempylidae** (Eocene to Recent; snake mackerels; escolars)
- Family **Trichiuridae** (Oligocene to Recent; hairtails; cutlassfishes)

Suborder **Scombroidea**
- Family **Scombridae** (= **Acanthocybriidae**; Eocene to Recent; mackerels; tunas)
- Family ***Palaeorhynchidae*** (Eocene to Miocene)

- Family **Istiophoridae** (Eocene to Recent; sailfishes)
- Family *Blochiidae* (upper Cretaceous to Oligocene)
- Family **Xiphiidae** (Oligocene to Recent; swordfishes)
- Family *Xiphiorhynchidae* (Paleocene to Recent)

Suborder **Luvaroidea**
  - Family **Luvaridae** (pelagic fish)

Suborder **Tetragonuroidea**
  - Family **Tetragonuridae** (squaretails)

Suborder **Stromateoidea**
  - Family **Stromateidae** (harvest fishes)
  - Family **Nomeidae** (shepherd fishes)

Suborder **Kurtoidea**
  - Family **Kurtidae**

Suborder *Ramphosoidea*
  - Family *Ramphosidae* (lower Eocene)

Suborder **Gobiformes** (Eocene to Recent)
  - Family **Eleotridae** (sleepers)
  - Family **Gobiidae** (gobies)
  - Family **Periophthalmidae** (mudskippers)
  - Family **Apocrypteidae**
  - Family **Taenioidae**
  - Family **Trypauchenidae**
  - Family **Benthophilidae**

Order **Scleropareioidea**
  - Family **Scorpaenidae** (upper Cretaceous to Recent; scorpion fishes; rock fishes)
  - Family **Triglidae** (upper Eocene to Recent; gurnards; sea robins)
  - Family **Caracanthidae**
  - Family **Pataecidae** (forehead-fish)
  - Family **Anoplopomidae** (sablefish)
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Family **Ophiodontidae** (cultus cod)
Family **Oxylebiidae**
Family **Zaniolepidae**
Family **Oplichthyidae**
Family **Congiopodidae**
Family **Platycephalidae** (flatheads)
Family **Cottidae** (sculpins)
Family **Cottocomephoridae**
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Family **Agonidae** (Eocene to Recent; sea poachers)
Family **Cyclopteridae** (lumpsuckers)
Family **Lipariidae** (sea snails)

Order **Cephalacanthoidea**
Family **Cephalacanthidae** (= **Dactylopteridae**; flying or long-finned gurnards

Order **Hypostomosoidea**
Family **Pegasidae** (sea moths)

Order **Pleuronectoidea** (= **Heterosomata**; Eocene to Recent; flounders; flatfishes; soles; halibut)
Suborder **Psettodoidea**
Family **Psettodidae**
Family **Bothidae**
Subfamily **Citharinae**
Subfamily **Paralichthyinae** (Miocene to Recent)
Subfamily **Bothinae**
Subfamily **Scophthalminae**
Family **Pleuronectidae** (halibuts; flounders)
Subfamily **Pleuronectinae**
Subfamily **Poecilopsettinae**
Subfamily **Paralichthodinae**
Subfamily **Samarinae**
Subfamily **Rhombosoleinae**

- Suborder **Soleiformes**
  - Family **Achiridae** (soles)
    - Subfamily **Achirinae**
    - Subfamily **Apoinichthyinae**
  - Family **Soleidae** (Eocene to Recent; soles)
    - Subfamily **Pardachirinae**
    - Subfamily **Soleinae**
    - Subfamily **Heteromycterinae**
  - Family **Cynoglossidae** (tongue fishes)

Order **Icosteoidea** (= **Malacichthys**; ragfishes)
  - Family **Icosteidae** (= **Acrotidae**)

Order **Chaudhurioidea**
  - Family **Chaudhuriidae**

Order **Mastocembeloidea** (= **Opisthomi**)
  - Family **Mastocembelidae**

Order **Discocephalioidea** (= **Echeneiformes**)
  - Family *Opisthomyzonidae* (upper Eocene)
  - Family **Echeneidae** (shark suckers; remoras)

Order **Plectognathoidea**
- Suborder **Balistoidea**
  - Family **Triacanthodidae** (Oligocene to Recent)
  - Family **Triacanthidae**
  - Family **Aleuteridae** (= **Monacanthidae**; file fishes)
  - Family **Triodontidae** (lower Eocene to Recent)
  - Family **Balistidae** (Oligocene to Recent; trigger fishes)
- Suborder **Ostracioidea**
  - Family **Ostraciidae** (Eocene to Recent; trunk fishes)
- Suborder **Tetraodontoidea**
  - Family **Canthigasteridae**
  - Family **Lagocephalidae**
  - Family **Colomesidae**

- Family **Tetraodontidae** (puffers)
- Family **Chonerhinidae**
- Suborder **Diodontoidea**
  - Family **Diodontidae** (lower Eocene to Recent)
- Suborder **Moloidea** (Miocene to Recent; ocean sunfishes; mola; headfishes)
  - Family **Molidae**

Order **Gobiesociformes** (= **Xenopterygi**)
  - Family **Gobiesocidae** (Miocene to Recent; clingfishes)

Order **Batrachoidea** (= **Haplodoci**)
  - Family **Batrachoididae** (toadfishes)

Order **Pediculatiformes**
- Suborder **Lophioidea**
  - Family **Lophiidae** (anglers)
- Suborder **Antennarioidea**
  - Family **Antennariidae** (frogfishes)
  - Family **Brachionichthyidae**
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- Suborder **Ceratioidea** (deep-sea anglers)
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